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OBSERVATIONS OF THE SENSES AND INSTINCTS OF THE RACCOON

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When an animal is free, observations of its behavior cannot usually be repeated in order to verify the observer's explanation of it. For example, Erasmus Darwin saw evidence of reason in the wasp when, as he averred, he saw a Sphex, with a prey too large for it to drag, cut off the wings, legs, and head of the prey, whereupon it easily transported the trunk and stored it. Fabre replied that Darwin had not seen a Sphex in this case but an insect which instinctively dismembers its prey and stores only the body. Recently one of my students reported that he had seen a hornet do this.

With observations so rare and isolated as these it will surely be long before different observers will agree in their interpretation of the behavior. Consequently, I report in what follows only observations of the raccoon which were made repeatedly. It may still be objected that the conditions were artificial. Yet when several raccoons are set free from captivity for an hour or two each day and their behavior noted the conditions appear so nearly natural that behavior observed in all the individuals would seem to be typical for this animal.

THE SENSES

Touch: The most conspicuous behavior of the raccoon seems to be associated with the sense of touch, which is highly developed in the palm of the forepaw and the tip of the nose. During their hours of activity the animals were most often busy in exploring with their paws the floor and objects on the floor of the room in which they were kept. The cage was an object of similar exploration. When the cage was moved the uncovered floor space excited this reaction with renewed activity. Dark places, as your pocket or a knothole, are explored by touch hundreds of times. Observers agree that the motive for this exploration is instinctive curiosity and I shall discuss this behavior further in connection with that topic. Notwithstanding the strength of the raccoon in clinging and climbing, no touch is softer or more gentle than that of his forepaws when engaged in this investigating activity.

An evidence that the nose is sometimes used for pure touch is the fact that these animals frequently investigated the experimenter's hands, and even his face, with the nose. This also seemed to be an affair of pure curiosity and quite breathless while it lasted, just as a human being may not breathe perceptibly when intent on some object. In fact this momentary stopping of respiration is given by Meumann [1] as one of the most marked physical accompaniments of human attention. This use of the nose as an organ of touch was observed on the sixth day after we received the raccoons and frequently thereafter. Occasionally they would both touch a strange object with the nose and sniff at it also.

I was unable to detect that the vibrissae were used as organs of touch, and perhaps this would be difficult to do unless one could have a blind animal under observation.

Taste: The raccoon's taste for sweets is especially marked. All other foods were promptly deserted for cane sugar by my animals, though Brehm states that the raccoon prefers "flesh" to other foods. My raccoons avoided all food which had a purely sour taste, yet ripe apples and peaches were eaten which have for human taste a slightly acid tang along with the sweet flavor. Unlike herbivorous animals the raccoon refuses to taste salt. I do not know of any carnivore which will accept salt or which frequents salt licks. Consequently the raccoon's rejection of salt may be a general characteristic of flesh-eating animals. Beyond these statements we can only enumerate the foods which raccoons accept readily, which of course give complex tastes.

Next to sugar the raccoons preferred boiled beef and they were almost equally fond of uncooked apples, peaches, plums, and cherries. My animals never ate the raw beef which we offered them a few times. Some raccoons have been forced to eat it but they appear not to thrive on such food. My raccoons were often seen to catch and eat flies. They would eat grains of corn, even when dry and hard, if they were hungry. Bread made of either corn-meal or flour was readily accepted. It seems evident, therefore that the raccoon in his native haunts lives upon forest fruits and buds, and upon flies, beetles, minnows, etc.

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[1] Meumann, E. Vorlesungen zur Einführung in die experimentelle Padagogik. Bd. I, p. 159, 2d. Aufl. 1911.

Brehm [2] says, "In respect to his food the raccoon is a true bear. He consumes everything that is eatable, but seems to be a real epicure who prides himself on picking out the best morsels, if only it is possible. The most different kinds of fruits, as chestnuts, wild grapes, maize, so long as the ears are not hard; fruits of every kind furnish valuable means of nourishment; but he tries to catch birds and their broods, knows how to steal upon a chicken or a dove, catches nimble fish, crabs and testaceous animals, and ventures at ebb-tide, for the love of such feasts, far out into the water. Especially does he like to eat oysters and understands how to open them skilfully."

Smell: So far as I could observe the raccoons did not often employ the sense of smell, though this may have been due to their captive condition. In no case did they seem to find pieces of meat on the floor by means of smell. If one of them saw a small piece of meat dropped in the hay on the floor he would search for it carefully but beyond a distance of a few inches he did not seem to smell it. They found small pieces of loaf sugar on the floor quite as promptly as they did meat, yet from the standpoint of the human sense of smell sugar has no odor.

In one case smell was evident. When the animals were to be fed the basin of food was usually placed on the step while the door was being unlocked. During this time all of the raccoons sniffed noisily at the crack beneath the door. When it was opened, however, they *looked* for the food basin. So in this case smell was evident only when sight could not be used.

On receiving the fifth raccoon, which was very young, I placed it on the floor of the room in which the older animals were kept. They showed both fear and curiosity in regard to it. After a time they came within two feet of it, stretching their muzzles toward it with slight sniffing. Finally they touched its fur with their noses. The males then took no further notice of the young animal but the female touched it with her nose many times during the following half-hour.

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[2] Brehm, A. E. Thierleben, Erster Band, Leipzig, 1875.

Living as they do, mainly in trees, and securing their food chiefly by means of sight, these animals may need to depend but little on the sense of smell. Doubtless they are susceptible to odors coming through the air, as the smoke of forest fires, but the two cases above described are the only ones which I observed of the use of this sense. I believe that they have no gift of trailing other animals as dogs do, though it has been assumed that they have the power to do so.

Vision: The raccoon has a keen sense of sight. As in the case of Clever Hans, a movement of the experimenter so slight as to be unconscious on his part was promptly seen by the animals and responded to as a food signal. Consequently it was necessary to make the movements involved in giving the animal a morsel of food even when he was not fed. Otherwise he would respond to the unconscious movements preliminary to feeding him and cease to pay attention to the different forms or sizes of the cards to which we wished him to respond. Attention to the experimenter's movements must have been established very early for within a week after we began work with the young animals one of them climbed to the top of a barrel on which the bottle of milk had been placed. It was impossible that he could have seen the bottle so his climbing for it must have been due to his having seen it placed there.

Later all of the raccoons recognized the food basin by means of sight and developed great cunning in their attempts to get food from it.

Hearing: This appears to be the special protective sense of the raccoon. The slightest sound produced (1st) perfect immobility, and (2d) fear and scurrying to the highest part of their place of confinement. If the experimenter tried during this fear to reach up and take hold of one of the animals it would retreat and snap though a moment before it was eager to be fed and quite willing to be handled.

Every sound at a distance was listened to intently for several seconds after the experimenter had ceased to hear it. On one occasion all the raccoons became still and yet the observers could hear no sound. Investigation showed that a man was trundling a wheelbarrow over the grass plot at least 100 yards distant from the house in which the raccoons were kept.

The sound caused by dropping on the floor a piece of meat, one-half the size of a grain of corn, was often heard by each of the animals. They turned directly toward the source of the sound. Hence they not only hear faint sounds but localize them well. Localization was further tested by putting raccoon No. 3 in a large box with a solid back. The experimenter then scratched on the outside of the back of the box with a small stick. The raccoon turned directly to the spot. The place was changed some two feet. He turned instantly to the new place and grasped with both forepaws at the exact spot. He did this repeatedly. His behavior suggests that localization of sound is much more definite than that of the human ear. His grasping at the spot might indicate that the raccoon catches some small prey partly by the aid of hearing.

If a raccoon which is working for meat hears another munching loaf-sugar he will at once stop work and approach the other in search of sugar. In this case the animals seem to have a definite sound-taste association.

On the principle that animals which make sounds hear sounds we may, in connection with hearing, mention the sounds which the raccoon is capable of making. A warning growl always accompanied eating when they were fed. When hungry they sometimes emit a sound about midway between a whine and a purr, "a whimpering cry." This sound is well known to woodmen and is far more characteristic of the young than of the adult animal. It has been described as varying from the quavering note of a "screech owl" to a sound like a colt's whinny, though I can detect no resemblance to the latter sound. It does vary from a sort of contented purr in the young to a rougher, higher pitched, whining sound when the animals are very hungry or when, in the case of my raccoons, they were trying hard to overtake the experimenter who was walking too rapidly for them to keep up with him. When forcibly held their whining and growling is somewhat similar to that of a dog. In fighting the animal gives short, sharp barks as he snaps.

Turning once more to the whining-purr, there is less and less of it (in captivity) as the animals grow older and only long waiting for food produces it. In the forest it may be used as a call to others. A very young raccoon, making this cry from loneliness or in search of its mother, will cease to make it if gently stroked or scratched.

Davis [3] describes the mother's warning note to the young which, doubtless, I have not heard.

INSTINCTS OF RACCOONS

I have already described the instinctive cry of the raccoon. It subsides into a whining purr of satisfaction as hunger is allayed. A young animal will drop off to sleep while quietly whimpering.

Sucking: The impulse to suck is ripe at birth, of course, and with it is a tendency to press with the forepaws on the breast of the mother. When a young raccoon is fed from a bottle the two forepaws are gropingly outstretched, then brought together and clasped just as a human babe sometimes clasps its hands without interlocking the fingers. Thus clasped they sink together down to the floor only to be outstretched again in blind and futile groping. The act is part of the sucking reflex and its persistence shows its instinctive character. The sucking impulse remained active until the animals were (as estimated) four months old. This is probably somewhat longer than its normal period. A slight tendency to lap milk appeared in the twelfth week. Hunger would have brought them to this mode of feeding much earlier. The sucking instinct may be perverted, the animal sucking parts of its own or its companion's body. This perversion waned, however, with the waning of the instinct and disappeared with it.

Creeping: The young raccoon seems to pass through a stage of creeping. The youngest one that I had under observation was not more than a month old when he was received. His movements over the floor were so different from those of the adult that they may be described only by the word, creeping. The forelimbs are widespread, the palms outstretched as if feeling the way. The body is propelled, therefore, chiefly by the hinder limbs which are wider spread than in the later walking. The whole movement is uncertain, staggering and tremulous, and frequently results in rolling over on the side. Hence, it is suggestive of creeping though it may be, instead, the beginning of the impulse to climb.

Climbing: This instinct involves the sense of support, which is present before the raccoon possesses either the strength or the muscular co-ordination necessary for climbing, and the impulse to cling to any support. The sense of support is best described by an example. When raccoon No. 5 was probably not more than two weeks old I placed him one day upon the top of a small closed box six inches high. He groped over the top of this box in the manner which I have described as creeping, with his forepaws extended, feeling the way. But the moment his paws felt the edge of the box the animal shrank back and began to grope in another direction. Again he would find the edge and again shrink back and start anew. Apparently at this age vision did not serve to show him that he might safely drop to the floor. It seems likely that this impulse enables the young raccoon to remain safely in a high nest, even though it were not enclosed. At any rate its advantage to a tree inhabiting animal is obvious.

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[3] Davis, H. B. Amer. Jour. of Psych. 1907, Vol. 18, pp. 454.

When the raccoon is a month old it is able to sustain its weight by clinging to a support by any one of its paws and this it does instinctively. It will hang thus from a rod or the experimenter's finger, unless it can feel a support beneath it. In the latter case it instantly releases its grasp and drops to the secure footing. One of the chief difficulties in handling raccoons is this instinctive tendency to cling to all nearby objects. In being put into a cage through the door the animal will lay hold of the sides with his paws and the difficulty encountered in disengaging him shows his remarkable strength.

As soon as the young raccoon can walk well any bush or tree arouses his impulse to climb. At first there is some awkwardness and two of our animals were seen to fall from a small tree, when about eight weeks old. A little later they could hardly be dislodged at all. After the animals ceased to follow the experimenter when set free they always ran to climb the nearest tree. As Brehm states, the raccoon often climbs along a branch with his back down "like a sloth or an ape." When the same writer says that the raccoon makes "leaps from one bough to another with unfailing certainty," his observations differ from mine. Instead of this my raccoons always laid hold of one bough before releasing the other. They go from one bough to another very quickly yet they rely much more on their strength in clinging than on their agility. In fact I tried to get the animals to leap from one box to another for food but they usually clung to the first box with their hind paws and, with only a sort of half leap, reached the second with their forefeet and pulled themselves upon it. Their climbing up the trunk of a tree is exactly like that of a bear.

Play: The raccoon is everywhere described as very playful. One would sit for a long time and play with his hind feet or the tip of his tail. Three were observed to play in this fashion for one and a quarter hours, with almost no pause. While my animals had to work twice a day for their food I observed only momentary play, or perhaps curiosity, as the tendency to pick up a straw or bit of cornhusk and roll it for a moment between their forepaws. In some degree, therefore, their play seems to depend on the possession of surplus energy. When well rested they played roughly with each other in mock fights, running and seizing each other gently with the teeth, rolling over and over in their tussles. In this play they would often climb to the shoulder of the observer, whereby he may learn both the strength of their grip and the sharpness of their claws. They also make pretense of biting your hand in play, a characteristic reaction of the pet raccoon.

Beckmann says, "In the numberless leisure hours which every captive raccoon has he does thousands of things in order to dispel the tedium. Now, he sits upright in a secluded corner, and with a most earnest expression he is busied in trying to tie a straw around his nose. Now, he plays thoughtfully with the toes of his hind foot, or snatches after the wagging end of his long tail. At another time he lies on his back and has a whole heap of hay or dry leaves hugged against his belly and he tries to tie down this loose mass by drawing his tail tightly over it with his forepaws."

The Impulse to Follow: After learning to walk the raccoons would all follow me, or anyone else, with the utmost eagerness. If I ran they struggled through the grass at their best rate, giving the instinctive cry more and more shrilly as I got further away from them, and ceasing to give it when they overtook me. In the middle of the seventh month this instinct to follow began to wane. When released from their place of confinement each one tended to go on an exploring tour of his own and to make for a nearby tree. At this time they would still follow if called. A month later no one of the four would follow at all, and their period of infancy was past.

A clear case of the inhibition of one instinct by another was observed in connection with the impulse to follow. The sixth raccoon which came into my possession had been made cross by teasing and would snap at any one who attempted to touch her. Notwithstanding this when I set her free in the meadow she followed me as the others had done. When I stopped she overtook me and halted at my feet. I then stroked her and picked her up. This I repeated many times. There was no snapping during this exercise in following, but when I tied the raccoon in her usual place and tried to pick her up she snapped at me viciously. Thus the following instinct, which is characteristic of the young raccoon, inhibited, momentarily, the fighting instinct which had been developed early in this animal by teasing. With the four full grown raccoons the condition is reversed. They will not snap at one who tries to pick them up when in their room, but they may do so when they are free.

Fear: As I have already stated, the raccoons showed fear. Like human beings they start at sounds but not nearly so violently nor so frequently as two coyotes which I had. The latter, of course, must escape from their pursuers by flight alone while the raccoon depends upon climbing and hiding. Like the dog they come to distinguish a threatening tone of the trainer and to retreat on hearing it. If hungry this has little effect on them for the thoughtful experimenter will give his animals little cause to fear him.

The sudden darkening of the room caused by the door's blowing shut produced in our young animals a panic of fear for a moment. This, with their fear of the young raccoon which I placed among them, is the only instance of fear of things which they saw.

Anger: The natural history accounts describe the raccoon as especially good-natured and so he is. Yet anger or ferocity was observed in these animals at about the twelfth week of their age. Though scrupulous care was taken to keep the animals tame they became fierce if they were left without being handled for a few days. In the fighting attitude the ears are laid back, the head lowered and the posterior portion of the body sharply humped up. Growling and unfleshing the teeth accompany this fighting attitude and, when provoked the raccoon is an ugly fighter. Intense anger and fear both act as purgatives.

Curiosity: All observers credit the raccoon with the possession of curiosity and he is likened to the monkey in this respect. The behavior which indicates curiosity is, however, associated chiefly with the sense of touch. The animals continually employ this sense in investigating the floor and all objects about them. Especially dark places, as your pocket, a knothole or a crevice, are explored by touch hundreds of times. It is no acquired trick that the raccoon puts his paw in your pocket, but a deeply rooted instinct. Even when hungry a raccoon which knows perfectly how to get food by operating some mechanism will stop work for a time in order to thrust his paw in your pocket or deep under your coat. Without exception they all carefully explored the bottom of the basin whenever fresh water was brought to them.

It may be that in nature they secure food by exploring dark crevices by touch but as my animals never obtained food in this way we should expect the impulse to have passed away unless it were genuine curiosity of a "disinterested" type.

A part of Beckmann's account of this behavior may be quoted, "Among the conspicuous peculiarities of the raccoon must be reckoned his boundless curiosity, * * * and his propensity for rummaging every nook and corner. * * * If he can get to a wall of masonry he scratches the mortar out of the joints with his sharp claws and causes incredible devastation in a short time. Like Jeremiah at the ruins of Jerusalem, he then sits down in the midst of his heaps of rubbish, looks sadly about him, and exhausted by his hard work, lifts his collar with his forepaws."

Sympathy: (?) These animals pay almost no attention to one another. Though one raccoon is retreating from you, growling and snapping, the others are in nowise disturbed. Their indifference to each other's behavior could hardly be more marked, and this fact must be taken account of in considering the question of imitation.

Dipping Their Food in Water: This peculiar instinct gives the raccoon two names. The Germans call him the "Waschbär," while science entitles him "Procyon lotor." Yet my raccoons did not always dip their food in water. No doubt this was partly due to their being fed together so that they formed the habit of eating rapidly. Moreover, they were, at first, fed only for operating some problem-box and this may also have tended to inhibit the instinct. Nevertheless, I do not believe that the raccoon in his native state will carry food very far for the purpose of "washing it." The impulse is present, of course, but it is no more invariable than any other instinct, and it has probably been observed most often in pet raccoons with a vessel of water always near them.

Sexual Instinct: No certain evidence of the presence of this instinct was observed until the twelfth month.

HABITS

Using the word habit in the natural history sense I may mention briefly some characteristic traits of the raccoon's behavior. In drinking they lap the water or milk but with the nose very close to the surface of the liquid. When heated by exercise they pant like dogs but with the tongue only slightly protruded.

There are two rather characteristic positions in sleeping. In one the animal lies on his back with his forepaws placed over his eyes. A young raccoon, when held and somewhat frightened, also puts both forepaws over his eyes, thus giving a somewhat comical appearance, suggestive of "hiding its face in its hands." Another position in sleep consists in rolling the body almost into a ball with the top of the head placed flat on the floor between the forelegs. In this position even the ears are hardly visible. Though the animal does sleep in other positions these two are most common. It would seem that the raccoon sleeps best, therefore, with his eyes not only closed but covered, and that for protection he depends most upon his lofty nest and its concealment from enemies.

Brehm says, "In May the female brings forth two or three, according to Audubon four to six, very small young ones in a rather carefully prepared den in a high tree." There were four young animals in the litter which I secured.

VISUAL DISCRIMINATION OF SIZE AND FORM IN THE ALBINO RAT

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One figure

In the exact experimental work of comparative psychology evidence of visual image formation has been obtained for all of the higher groups of vertebrates, but few investigators have attempted to determine the accuracy of the animal's perception of outlines.

L. J. Cole, (1907) obtained evidence of the perception of size in the frog. Casteel, (1911) working with the turtle, found that it could distinguish slight differences in the breadth and direction of lines, but did not discriminate between similar patterns. For the birds, Porter, (1904-06) has demonstrated the ability of the English sparrow and cow-bird to discriminate printed patterns and, less accurately, tridimensional objects. In his work with the dancing mouse Yerkes, (1907) obtained no reactions to form and concluded that the perception of form has little importance in the activities of the mouse. Waugh, (1910) in similar experiments, obtained only slight evidence of form discrimination and was led to the same conclusion. By L. W. Cole, (1907) the raccoon has been trained to distinguish perfectly between objects of different size and form, square and circular cards, etc. Kinnaman, (1902) found that his monkeys could compare the size of the food boxes used and form some absolute standard of comparison. They also distinguished between vessels of different form but did not recognize differences in printed patterns.

The present investigation has attempted to determine the visual acuity of the rat, making use of the "form and size methods" (Washburn, 1908). Like the mouse, the albino rat is without an area centralis (Chievitz, 1891 and Slonaker, 1897), and the retina contains only rod-like sensory elements. From the likeness of structure and habitat, a similarity of visual function is to be expected.

The author is indebted to Professor John B. Watson for helpful suggestions and criticism, and to Miss Cora D. Reeves for the data in experiment 11 and for valuable assistance in other parts of the work.

APPARATUS AND METHODS

Throughout the greater part of the experimental work a discrimination box, modified after the type designed by Yerkes, (1907), was employed. This box was used by Hoge and Stocking, (1912). A diagram of it is given in figure 1. The box con-

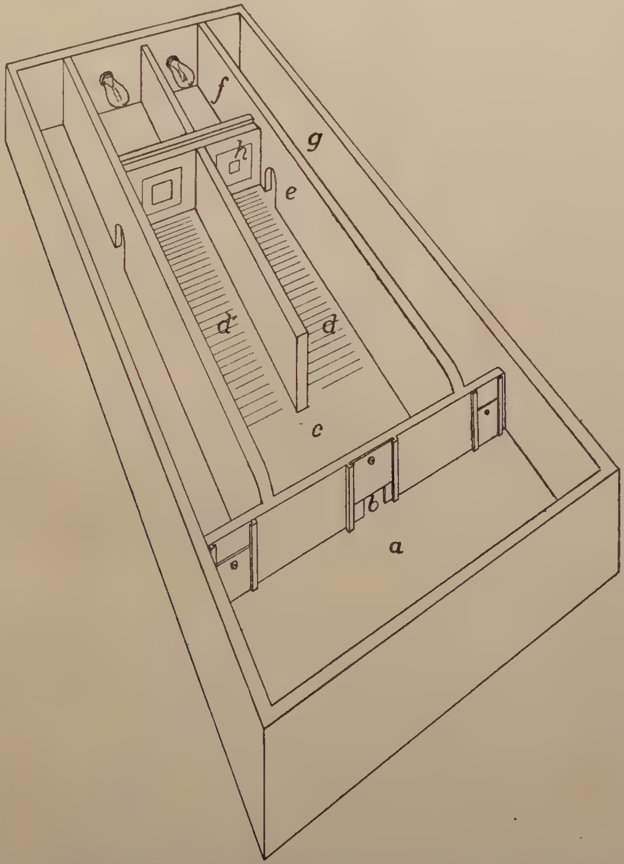

FIGURE 1. Discrimination box. a, Starting compartment; b, sliding door; c, discrimination compartment; d, d′, passages wired with electric grill; e, door to food compartment; f, light compartment; g, food compartment; h, reversible frame containing the translucent forms used as stimuli.

sists, essentially, of a starting-room, a, leading by a door into the discrimination compartment, c, in which the choice of two passages is offered to the animal. The forms to be discriminated are placed at the ends of the passages so that the animals must go directly toward them in order to reach the doors leading to the food compartments, g, g. The forms consist of metal plates, pierced by suitable openings and backed by opal flashed glass. They are fastened in a wooden frame, h, which may be lifted out of the box and inverted in order to transpose the stimuli. Sixteen candle power, carbon filament lamps, placed in a compartment, f, behind this frame, illuminate the forms brightly. The passages, d, d, are wired with an electric grill by which punishment may be administered.

Food, given in the compartments g, g, after a correct choice, and punishment, given in the passages after an incorrect one, were used as motives for discrimination. The rats were allowed to run from the starting box to the food compartment and were then lifted back to the starting box. In the first experiments punishment did not seem to give good results and it has been used as a motive only where indicated in the descriptions of experiments.

Since none of the work was quantitative, no regular system was followed in reversing the stimuli, but care was taken that the number of times that the positive stimulus was exposed in each passage should be equal in any given series of trials. In spite of this the animals, especially those which were punished, showed a strong tendency to form position associations, going again and again through one of the passages even when severely punished.

At different times during the experiment some of the rats learned to react to the noise made in reversing the forms, to the position of the experimenter during the trials, and possibly to variations in the time between successive trials. They usually tended to avoid the passage in which they had last been punished, and learned readily to follow simple rhythms of alternation. In experiments with Rat No. 6 it was customary to electrify the punishment grill before admitting the animal to the discrimination compartment, and there is some evidence that she learned to test the grill with her vibrissae before venturing over it.

Whenever any such reactions were discovered, immediate attempts were made to eliminate them, and control series were given to determine their importance in the total reaction. In general, it was only in the more difficult problems that the animals fell back upon these secondary criteria. The sense of smell never seemed to play any part in the reaction.

As a rule, each animal was given 20 trials a day, but this number could not be adhered to strictly. With the type of apparatus used, 50 per cent of error indicates that the animals are not discriminating, that their movements are due to chance, and it was found during succeeding experiments that a much lower percentage of error, not more than 25, upon several consecutive days was necessary to give conclusive proof of discrimination. An animal might make 90 per cent of correct choices in a series of 20 trials, but such a high average, if due to chance, never persisted through two consecutive series. The percentage of error is not always a safe measure of the animal's ability to discriminate between the stimuli. It does not take into account the fluctuations of attention or the difficulties of associative and learning processes. For this reason the behavior of the rats in the discrimination compartment has been given special emphasis.

ANIMALS

In the experimental work albino rats alone were used. Trapped specimens of *Mus rattus* proved to be too wild for experimental purposes, and domesticated races of pigmented rats have shown no marked superiority to the albinos in visual discrimination, so no extensive comparison between pigmented and non-pigmented races was undertaken.

The rats used differed considerably in age and in behavior at the beginning of the experiments.

No. 1. Female, 11 weeks old when given this problem; vigorous, active, and stable.

No. 2. Female, from the same litter as No. 1; very large and inactive.

No. 3. Female, from the same litter as No. 1; stunted in growth, very excitable, and easily frightened.

No. 4. Female, about two months old; large and active.

No. 5. Female, from same litter as No. 4; ill during the first part of the experiment, small but very active.

No. 6. Female, age unknown; she had given birth to one litter which she devoured; very tame, accustomed to being handled. Judged from her general behavior, this rat seems to use vision to a greater extent than the others.

No. 7. Female, age unknown; forms position associations very readily.

EXPERIMENT 1. DISCRIMINATION OF FORM

Apparatus: The discrimination box; two standard stimulus plates showing a square and a circle of equal area (56.548 sq. cm.). The experiment was conducted in a darkened room. Rats Nos. 1, 2 and 3 were used. Since they showed no preference for either form, the square was chosen arbitrarily as the positive stimulus. The motive differed for each of the animals.

No. 1. Food after a correct choice only.

No. 2. Food after every trial, punishment after an incorrect choice.

No. 3. Food after correct, punishment after incorrect choice.

During the first part of this experiment no precautions were taken to eliminate other than visual stimuli to which the rats might learn to react. The noise made in reversing the stimuli and other movements and sounds made by the experimenter were thus available to the animals as indices of the passage to be chosen.

Table I, giving the percentage of error in each 100 trials, shows the record made by the animals in 1000 trials. The percentage of error was never small enough to justify the conclusion that the animals were reacting to the difference in the visual stimuli. The occasional low percentages are to be explained by the appearance of reactions to sound, or to other accidental stimuli.

TABLE I

DISCRIMINATION BETWEEN SQUARE AND CIRCLE OF EQUAL AREA. PERCENTAGE OF ERROR IN EACH CONSECUTIVE HUNDRED TRIALS

No. trials	100	200	300	400	500	600	700	800	900	1000	Average
Rat No. 1	47	39	48	45	40	37	47	37	60	53	45.8
Rat No. 2	65	46	54	71	49	59	64	48	52	46	55.4
Rat No. 3	41	37	36	38	43	55	51	43	40	55	43.9
Average	51	40	46	51	44	50	54	43	51	51	48.3

The average percentage of error is slightly below 50 and this may be explained by the training method employed, which frequently allowed the animals to make several correct trials before the stimuli were transposed. The effect of this method appears in the first 500 trials (46.8%) but disappears in the last 500 (49.8%), in which an effort was made to eliminate all secondary criteria by which the animals might regulate their reactions.

Since the rats learned to react to sound and to other accidental stimuli it is certain that they were not indifferent to the motives provided and that their failure to respond to the visual stimuli was not due primarily to a fault in the technique of experimentation. The cause of their failure is to be sought in the nature of the visual stimuli, or in some defect in their visual apparatus. After a few hundred trials the animals became almost machine-like in their actions, the choice of the passage taken usually having a definite relation to the success or failure of the preceding trial. They rarely paused in the discrimination compartment or passages and did not seem to attend to the stimuli. It seemed, then, that the failure might be explained by this inattention and a second experiment was therefore undertaken in the hope of training the rats to attend to the illuminated areas.

EXPERIMENT 2. MOVING STIMULUS

Apparatus: The discrimination box with the forms as in experiment 1. A revolving sector was introduced into one of the light compartments (figure 1, f) between the light and the metal form. The sector was composed of two vanes, each of 45 degrees, and was turned by a small motor at a speed of five revolutions per second, thus interrupting the light 10 times per second and producing a regular flickering. It was expected that this flickering light, simulating movement, would hold the animal's attention, and that, by decreasing the size of the sector and increasing its speed, the factor of movement might be gradually eliminated and the attention transferred to the difference in form. The square and circle were retained as stimuli and the sector was kept constantly behind the square, the forms being reversed as usual.

In the first series of trials given after the introduction of the sector all the rats showed evidences of fear, refusing to go toward the interrupted light or, at first, even into the discrimination compartment. In accordance with the custom of training against a preference the rats were required to select the interrupted light. After the first 20 trials the animals gave no further signs of attention to the flickering stimulus. Increase or dimunition in speed of rotation produced no change in their behavior. After 200 trials rat No. 2 became stubborn under punishment and had to be removed from the experiment.

As shown in table II, there was no decrease in the per cent of error after 500 trials. The rats did not learn to react to the stimulus although at first they had seemed to be disturbed by it.

EXPERIMENT 3

The size of the sector and its speed of rotation were next increased so that a marked difference in the brightness of the forms was produced.* For rat No. 1 a sector of 270 degrees was used. She learned to react to the difference in brightness and a change to the original speed of rotation did not affect the reaction. The size of the sector was then reduced to 180 degrees and later to 90. Each change was followed by a sudden increase in the per cent of error, then a gradual improvement in discrimination. When the sector was reduced to 75 degrees the rat failed to discriminate and soon ceased to attend to the stimulus (table III). The chief interest of this experiment lies in the fact that by a gradual increase in the similarity of the stimuli the rat could be trained to respond to a difference to which it had formerly given no attention.

EXPERIMENT 4

Since the animals did not distinguish between the square and circle, another experiment, apparently involving a greater difference, was undertaken. A circle, 30 millimetres in diameter, was used as the positive stimulus and two circles, 21.2 millimetres in diameter and 40 millimetres apart in a horizontal line, as the negative. Rats Nos. 3 and 7 were given this problem.

Table IV gives the percentage of error for each 100 trials and shows that there was no discrimination of the stimuli, even after 1000 trials. The animals ran through the discrimination compartment without a pause and never attended to the stimuli.

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* Hoge and Stocking (1912), have shown that differences in brightness are discriminated by both albino and black and white rats.

TABLE II

Percentage of Error in Daily Tests with Interrupted Light

Rat No. 1		Rat No. 2		Rat No. 3	
Trials	%	Trials	%	Trials	%
20	40	20	45	20	50
20	35	20	40	20	65
20	45	20	60	20	35
20	35	20	65	20	45
20	40	20	35	20	45
20	30	20	30	20	80
20	55	20	35	20	80
20	30	20	40	20	40
20	35	20	40	20	55
20	30	20	50	20	55
20	35	20	40	20	55
20	45	20	55		
20	50	20	50		
20	50	20	25		
20	50	20	40		
10	50	20	55		
20	40	20	85		
20	50	20	50		
20	45	20	50		
20	45	20	35		
20	45	20	45		
20	60	10	40		
20	45	10	60		
20	45	20	55		
20	90	10	60		
20	70	10	50		
20	50	10	60		
20	80	10	50		
20	40	10	60		
		10	40		
		10	70		
630	47.4	560	59.8	220	55.0

TABLE III

Percentage of Error with Large Sector. Rat No. 1

Size of Sector	No. Trials	%
270	20	40
“	20	40
“	20	25
“	20	35
“	20	45
“	20	15
“	20	35
“	20	30
“	20	10
180	20	40
“	20	25
“	20	20
“	20	10
90	10	20
“	20	50
“	20	25
“	20	45
“	10	30
“	20	15
“	20	35
“	20	10
75	10	20
“	20	50
“	20	55
270	20	0
90	10	50
“	10	40
“	10	20
“	10	10
45	10	20
90	10	60
“	10	20
“	10	60
“	10	50
“	10	70
“	10	30
“	10	30
“	10	30
“	10	30
“	10	10
“	10	30
“	10	20
“	10	20

TABLE IV

DISCRIMINATION BETWEEN ONE AND TWO CIRCLES OF EQUAL AREA. PERCENTAGE OF ERROR IN EACH HUNDRED TRIALS

No. trials	100	200	300	400	500	600	700	800	900	1000	Average
Rat No. 7	48	50	54	58	55	59	54	61	54	56	54.9
Rat No. 3	54	47	60	56	62	48	48	47	56	51	53.1

EXPERIMENT 5

This experiment was similar to the preceding, but instead of circles the forms used were two illuminated lines, 2 by 60 millimetres, one horizontal and one vertical. Rat No. 2, at the age of seven months and after about 2000 trials in other experiments, was given this problem After the experiment with interrupted light she had been trained to react to differences in brightness so that, at the beginning of this experiment, she attended to the illuminated forms. After 150 trials she began to show evidence of discrimination, hesitating and apparently looking at the forms before choosing one of the passages.

Table V gives the daily records for 760 trials. After 300 trials there was constantly more than 80 per cent of correct choice, and since control series in which both lines were placed horizontally gave 50 per cent of error, this was taken as sufficient evidence of discrimination. Control series in which the relative brightness of the forms was altered did not affect the reaction, while any great change in the shape of the forms themselves caused a complete failure.

EXPERIMENT 6

When the reaction to the lines was firmly established an attempt was made to determine the animal's ability to distinguish lesser differences. For this purpose two of the standard forms were provided with sliding metal plates, adjustable in two directions, so that the openings could be varied from a narrow line to a square or rectangle. These were first set as lines, 20 by 60 millimetres, and substituted for the horizontal and vertical lines used in the preceding experiment. By shortening and widening the lines the contrast between them could be reduced until both became squares, equal in area.

TABLE V

Discrimination Between Vertical and Horizontal Lines. Rat No. 2

Trials	Per cent Error	Trials	Per cent Error	Trials	Per cent Error	Trials	Per cent Error
10	40	140	30	340	30	560[1]	40
20	40	150	30	360	10	580	15
30	50	160	20	380	10	600	20
40	30	180	40	400	15	620	25
60	50	200	35	420	25	640	20
80	30	220	25	440	25	660	10
90	60	240	30	460	20	680	15
100	40	260	45	480	10	700	20
110	30	280	15	500	5	720	25
120	50	300	15	520	20	740	20
130	50	320	15	540	10	760	10

[1] At this point in the experiment No. 2 developed a bronchial disease which has made her later records somewhat irregular.

Table VI shows the changes made in the form of the stimuli and the percentages of error obtained in this experiment. Rat No. 2 gave certain evidence of discrimination between the 12 by 50 millimetre rectangles, and seemed to recognize the lesser differences without great difficulty.

TABLE VI

Discrimination of Form. Rectangles with Their Long Diameters at Right Angles

Size of Rectangles	No. Trials	Per cent Error	Size of Rectangles	No. Trials	Per cent Error
2 x 60	20	10	12 x 50	20	25
"	20	10	"	20	20
"	20	15	"	20	10
			"	20	15
12 x 50	20	25			
"	20	25	15 x 40	20	20
"	20	20	"	20	25
"	20	10	"	20	20
"	20	5			
"	20	20	20 x 30	20	10
"	10	10			
"	20	15	25 x 25	20	60
"	20	20			
			20 x 30	20	45
			"	20	60
			"	20	30

The percentage of error did not increase above 25 at any time during the experiment and the fact that no perfect records were made is due, at least in part, to the state of the animal's health. She suffered at this time from a pulmonary trouble which constantly distracted her attention from the stimuli.

Control experiments showed that the rat was not depending upon brightness, sound, or position in making the discrimination and her behavior in the discrimination compartment offers the best evidence that she was really attending to the visual stimuli. During experiments 1 and 2 she had always hesitated for a long time before venturing from the starting box to the discrimination compartment, finally dashing through to the food box as quickly as possible, avoiding the punishment grill by long leaps. When a marked difference in the brightness of the forms was introduced she began to pause in the discrimination compartment, swaying back and forth between the two passages before choosing. As her proficiency in discriminating differences in brightness increased, the time spent in choosing diminished until the reaction became almost instantaneous. With the greater number of correct choices her attempts to avoid the punishment grill were less marked. With the introduction of the lines as stimuli the hesitation between the passages again appeared, increasing and diminishing gradually after each change in the stimuli.

From the percentages of error it is evident that the animal could distinguish between the narrower rectangles. Her behavior in the discrimination compartment indicates that the discrimination was more accurate than the percentage records would seem to show, since they include all the trials made without regard to accidental distraction of attention. After the first day's work with the 20 by 30 millimetre rectangles, when 18 out of 20 trials were correct, the form of the stimuli was changed as a control. With the new forms there was 60 per cent of error, showing that perception of form was involved in the former reaction, but unfortunately this short interruption was sufficient to break up the association and in the next 300 trials there was 45 per cent of error with complete loss of attention.

EXPERIMENT 7. DISCRIMINATION OF SIZE

Apparatus: The discrimination box; two circles of 30 and 50 millimetres diameter respectively as stimuli. In the type of apparatus used the illumination of the two circular openings used as stimuli is equal per unit area, but since the flashed glass forms a total diffusing surface it acts as a direct source of illumination for the two passages. Consequently the brightness of the passages differed appreciably, being directly proportional to the areas of the circular openings. For the experimenter the difference in size between the stimuli was so much more evident than the difference in brightness that this latter was not considered at the beginning of the experiment.

Rats Nos. 4, 5 and 6 were used, with food, punishment, and food and punishment as motives. After 200 trials all began to show evidence of discrimination, but it required more than 500 trials to establish the association thoroughly. Even after 700 trials No. 5 was very uncertain in her reactions. Table VII shows the daily percentages of error in this experiment.

TABLE VII

Discrimination of Size. Circles 30 and 50 Millimetres in Diameter as Stimuli

No. of Series	Per cent of Error			No. of Series	Per cent of Error		
	Rat No. 4	Rat No. 5	Rat No. 6		Rat No. 4	Rat No. 5	Rat No. 6
1	45	25	55	23	15	25	40
2	55	60	35	24	20	30	10
3	50	40	45	25	25	25	0
4	45	40	35	26	15	30	10
5	40	45	40	27	20	35	5
6	55	45	35	28	25	20	15
7	55	40	45	29	10	30	20
8	35	70	60	30	20	20	10
9	40	40	20	31	15	35	0
10	45	45	45	32	5	15	20
11	30	35	60	33	10	35	0
12	45	45	50	34	5	10	20
13	40	65	45	35	0	25	20
14	35	25	40	36	10	15	10
15	40	45	45	37	0	25	10
16	45	35	15	38	5	40	20
17	35	35	30	39	0	15	20
18	30	65	40	40	15	20	30
19	40	10	35	41	0	0	10
20	15	55	35	42	0	30	20
21	10	35	30	43	0	30	0
22	30	55	10				

Under the conditions of the experiment it was uncertain whether the animals were reacting to the difference in size of the circles or to the difference in the brightness of the passages. A few control tests (table VIII) showed conclusively that the discrimination had been made upon the basis of the difference in the brightness of the passage only. The rats had been choosing the larger circle and when the relative brightness of the two was changed they chose always the brighter passage, regardless of the size of the forms. The slight difference in brightness was evidently more easily associated with the motive than was the difference in the size of the circles.

TABLE VIII

CONTROL ON EXPERIMENT 7

Nature of the Stimuli	Rat No. 4		Rat No. 5		Rat No. 6	
	Trials	Per cent Error	Trials	Per cent Error	Trials	Per cent Error
Illumination of larger circle reduced; brightness of passages equalized....	50	44	30	60	10	50
Size of circles equal; illumination unequal; animals chose the brighter...	10	0	10	10	..	..
30 and 50 mm. circles; the 30 mm. more brightly illuminated.........	...	..	20	95	10	50
30 and 50 mm. circles; the brightness of the passages equalized by reflected light......................	10	40	10	60	10	50
30 and 50 mm. circles; the floor of the passage to the 30 mm. illuminated brightly........................	10	60	10	80	10	60

EXPERIMENT 8

The preceding experiment was continued with the element of brightness eliminated. A 32 c. p. lamp was suspended six feet above the experiment box, so that the two passages were brightly illuminated (table IX, illumination 1). Later, the intensity of this light was increased until the difference in the brightness of the passages was reduced below the human threshold and, consequently, much below that found to exist for the rat (table IX, illumination 4). The 30 and 50 millimetre circles were retained as stimuli.

At first the animals failed to discriminate between the circles, but after 100 trials No. 4 showed evidences of discrimination, and in 200 trials learned to choose the larger circle accurately.

The other rats were slower in learning and required from 600 to 800 trials. When they had learned the problem they were given control series similar to those outlined in table VIII, but in this case the results were quite different. Changes in the relative brightness of the passages and forms did not affect the accuracy of the reaction, while reduction of the difference in size caused an increase in the per cent of error. In order to make certain that the rats were not reacting to the movements of the experimenter a test series was given by another person and although the animals were excited by the change they still made above 70 per cent of correct choices.

TABLE IX

Discrimination of Size. Brightness Factor Eliminated

Rat No.						Rat No.						Rat No.					
4		5		6		4		5		6		4		5		6	
No. Trials	% Error	No. Trials	% Error	No. Trials	% Error	No. Trials	% Error	No. Trials	% Error	No. Trials	% Error	No. Trials	% Error	No. Trials	% Error	No. Trials	% Error
10	50	10	60	10	40	20	0	10	60	20	45			20	30	20	15
10	30	10	50	10	50			10	30	20	45			20	25	20	20
10	90	10	30	10	50			10	40	20	50			20	25	20	15
10	30	10	50	10	50			10	40	10	30			20	20	20	5
10	20	10	50	10	50			20	50	10	50			20	20	20	10
10	30	10	10	10	50			20	50	10	30			20	10		
10	15	10	50	10	20	Illumination 1								20	10		
10	30	10	20	10	30			10	30	10	50			Ill. 4			
10	20	10	30	10	30			20	75	20	25			20	30		
10	15	10	20	10	30			20	55	20	25			20	20		
20	35	10	50	10	40			20	25	20	10			10	30		
20	10	10	40	10	40			20	60	20	55			10	20		
20	5	10	50	10	40			20	50	20	20			10	30		
20	10	10	40	10	30			20	35	20	15			10	20		
20	10	10	30	10	60			20	45	20	25			10	10		
20	5	10	40	10	70			20	20	20	10			10	90		
Illumination 4								20	20	20	10			10	50		
20	20	10	50	10	50			20	35	20	25			10	20		
20	10	10	20	20	50			20	15	20	10			10	30		
10	10	10	60	20	45			20	15	Ill. 4							
												300.		790.		630.	

EXPERIMENT 9

As soon as definite evidence of size discrimination was obtained an attempt was made to determine how small a difference the animals could distinguish. The size of the smaller circle was increased to 40 millimetres, the 50 millimetre circle being retained as the positive stimulus. Rat No. 4 learned to distinguish between these circles, but after 200 trials grew inattentive. Punishment was introduced to strengthen the motive and was continued throughout the third 100 trials (table X). The punishment was not associated with the stimulus and served only to confuse the rat so its use was abandoned. After 200 more trials the association was restored, but further attempts to reduce the difference between the stimuli produced an uncertain reaction. The smallest difference which the rats can distinguish, under the conditions of the experiment, is about two-fifths of the area of the larger circle.

TABLE X

Discrimination Between Circles of Different Size. Rat No. 4

Size of Circles	Trials	Per cent Error
50 and 30	10	0
50 and 40	20	15
“ “ “	20	20
“ “ “	20	10
“ “ “	20	25
“ “ “	20	0
“ “ “	20	20
“ “ “	20	10
“ “ “	20	15
“ “ “	20	25
“ “ “	20	40
“ “ “	20	25
“ “ “	20	35
“ “ “	20	30
“ “ “	20	50
“ “ “	20	60
60 and 30	20	5
50 and 30	20	40
50 and 30	20	15
“ “ “	20	40
“ “ “	20	20
“ “ “	20	20
“ “ “	20	20
“ “ “	20	20
“ “ “	20	20
“ “ “	10	10
“ “ “	20	10
50 and 40	10	30
“ “ “	10	30
“ “ “	10	30
“ “ “	10	20
“ “ “	10	10
50 and 45	20	60

EXPERIMENT 10

In the preceding experiments it appeared that the principal fault in the method of experimentation lay in the fact that the rats did not attend readily to the stimuli. Those which learned to react to differences in size or form had first learned to attend to brightness differences. From this it seemed probable that animals which were attending to the stimuli and reacting to differences in size might be trained without great difficulty to attend to differences in form.

Two forms, a square of 1600 square millimetres area and a circle of 706 square millimetres, were substituted for the forms used with rat No. 6 in experiment 9. The animal (No. 6) discriminated between these immediately, choosing the square. The area of the circle was gradually increased to 1200 square millimetres at which point the rat failed to react. This process of starting with a wide difference in area and gradually decreasing it was repeated three times, but whenever the area of the circle became more than three-fourths that of the square the rat ceased to react to the difference. After 600 trials there was no evidence that she could discriminate form.

With rat No. 4 a six pointed star was used as the positive stimulus, a circle of varying size as the negative. No. 4 chose the star so long as the difference in size was great, but when the area of the circle became more than three-fourths that of the star, the reaction became uncertain or broke down entirely.

With rat No. 5 two circles of a combined area of 706 square millimetres area (see experiment 4) were used as the negative stimulus, and a square of varying area as the positive. Starting with a square of 3600 square millimetres area, the area was reduced to 1225, at which point discrimination failed. This was repeated twice but the reaction always became uncertain when the difference in size became less than the area of the smaller form.

Later, with rat No. 6, a 40 millimetre square was used as the positive stimulus, and the negative stimulus was varied in form, its size being kept less than three-fourths that of the square. Circles, triangles, and various other forms were used. After the first few changes the rat was no longer disturbed by alterations in the form of the stimulus and chose the larger without hesitation. But whenever the difference in size was reduced below the threshold (experiment 9) she fell back upon position associations and failed to discriminate. In several of these series the rat chose the form of greater area, even when the other appeared larger when viewed as a unit of light and shade.

From these experiments it appears that the rats, in discriminating between objects of different size, do not perceive or do not attend to differences in form. Further data, obtained from rats 4 and 6 when offered a choice of two new forms of unequal size, support this view.

EXPERIMENT 11

Since the discrimination box places the animals under somewhat unnatural conditions a few tests were undertaken under an environment more nearly approaching the normal.

(a) Two cardboard food boxes were constructed, the one rectangular, the other pyramidal in form and having small openings in the sides to admit the rats. The exposed faces of the boxes were of equal area (128 square centimetres) but, owing to the sloping surface of the pyramid, they differed somewhat in brightness. Food was given in only one of the boxes and they were interchanged irregularly to avoid position associations.

Of the three rats required to choose between the boxes not one showed any evidence of discrimination after 150 trials. All formed position and rhythm associations but did not distinguish between the boxes in any way.

(b) Rat No. 1 was trained to go to a large square of flashed glass supported in an upright position upon the floor of the laboratory. After a few trials she learned to run directly to the square from a distance of two or more feet, passing behind the glass to get a bit of food. When this association was established a small piece of glass, one centimetre square, was placed beside the larger (12 by 12 centimetres). The rat sniffed at the small glass only once, then gave it no further attention. When a plate of 25 square centimetres area was substituted for the smaller square, the rat became confused and failed to choose the larger. After 40 trials, however, she began to avoid the small square and made a record of 17 correct choices in 25 trials. A rectangle of half the area of the larger square was then used as the negative stimulus. In the first 20 trials the rat made only five per cent error, then became frightened and in 200 trials since has shown no evidence of discrimination.

From this experiment it appears that the rat can distinguish great differences in size without difficulty. With slighter differences, however, the dependence upon kinaesthetic sensations appears, just as in the discrimination box, and learning does not seem to be any more rapid. The objection to the unnaturalness of the discrimination apparatus does not seem, then, to be a very serious one.

EVIDENCE FROM THE RAT'S BEHAVIOR IN THE DISCRIMINATION COMPARTMENT

In the descriptions of the experimental work the percentage of error has been employed to express the rat's ability to discriminate, since a great number of correct choices forms the most certain evidence, but in all the experiments, where positive results were obtained at all, the rats showed a recognition of the difference between the forms before the percentage of error was reduced below 50. In the unsuccessful experiments, after the first 100 trials, the animals became almost machine like in the regularity of their movements. There was seldom a pause in the discrimination compartment and the choice of a passage usually followed some definite rhythm. In experiments 3, 5 and 7 the beginning of discrimination was marked by long hesitation with a swaying back and forth between the passages. In the early stages of learning a correct choice more frequently followed where the animal hesitated than when it made a rapid choice. Later in the experiment choice by negation seemed to become the more important method of eliminating error. The rats chose a passage quickly, and if it were wrong, turned back when about eight inches from the stimulus. Choice by affirmation never seemed to be very effective, even with the best trained rats. They would frequently make a correct choice, then hesitate, turn back, and compare the forms.

When responding to visual stimuli they showed a careful attention to the illuminated forms, frequently returning from the food compartment to sniff at them after an incorrect choice. Failures more often followed after evident inattention.

At the introduction of any new element into the discrimination box, as when swinging doors were placed in the food boxes or when the passages were repainted, the rats became very much excited, refusing to leave the starting box or to approach the new object. This type of behavior was very marked in experiment 2 when the revolving sector was introduced, and shows unmistakably that the rats perceived the moving shadow, although they did not associate it with the motive. Changes in the brightness relations of different parts of the box were followed similarly by confused reactions.

The responses to sudden changes in the form of the stimuli are of importance as evidence of discriminating ability. Rat No. 6 was choosing the larger of two circles accurately (100%). Two squares of the same area, respectively, as the circles, were substituted for the circles and during the next 10 trials No. 6 was greatly disturbed, running in and out of the starting box, creeping a little way down the passages, then turning back. She attended to the squares as to something new. There had been no noise to account for this behavior and it is not probable that the new forms had any peculiar odor, so it seems that the rat must have been disturbed by the change of form.

This is only one instance of a type of behavior which appeared, to a greater or less extent, throughout all the experiments whenever the form of the stimuli was changed. It suggests that the animals perceived the difference, although they never associated it with the motive, and raises the question whether the discrimination method offers a fair test of the animal's discriminative ability.

SUMMARY OF RESULTS

In all the records there is a constant deviation in the percentage of error, and a series of 20 successive correct trials is very rare. Sudden increases in the number of mistakes may frequently be explained by the physical condition of the animals. If they are fed too much or too little, their attention to the stimuli is affected and the percentage of error increases. When punishment is used, the rat's fear of the punishment grill after too severe a shock causes irregularities in the records.

Making allowance for such deviations, the selection of the vertical line 164 times in 200 trials (experiment 5) proves that rat No. 5 could distinguish between the vertical and horizontal lines. In discrimination of size, the record of only 14 mistakes in 150 trials shows that rat No. 4 could discriminate between the 30 and 50 millimetre circles.

The number of animals used in the experiments has been small, necessarily, since the time required for each series is considerable. The rats show marked individual differences and all vary from day to day in their attention to the problem. The quantitative results are therefore only approximate. The tests for the threshold of form discrimination have been carried scarcely far enough to give definite results, and the data at hand are confused by the illness of the rat (No. 6) but it seems probable that she could distinguish between the 20 by 30 millimetre rectangles used in experiment 6. The difference between these forms is scarcely greater than that of the stimuli used in experiments 1 and 4, so this difference must lie somewhere near the threshold for the conditions given.

In the discrimination of size the records of experiments 9 and 10 indicate that the rat can distinguish a difference of one-fourth the area of the larger circle (2000 square millimetres). Reduction below this limit caused uncertainty of reaction and loss of attention. In addition to their ability to compare and choose between the stimuli, the rats are able to fix upon a rough standard of size. In choice by affirmation and negation they tended to go toward a circle of more than 40 millimetres diameter and to avoid one of less than 30 millimetres. But when both circles were made larger than this standard the rats still chose the larger of the two by comparison.

The long failure to react to the interrupted light in experiment 2 suggests that the factor of movement may play a less important part in the activities of the animals than is generally supposed; that an accustomed moving object is no more effective in catching and holding the attention than is a stationary one.

THE NATURE OF THE RAT'S IMAGE PERCEPTION

The rat perceives brightness differences readily, but ordinarily without attention to the nature of the image. Animals which have been trained to go to a white food dish will run to any white object. Absolute size is not so easily recognized, but greatly different areas are distinguished without difficulty. The perception and recognition of form seem to be most difficult for the animal and to require an unusually close attention. In these respects the rat's visual perceptions resemble closely human perception in the extreme peripheral field. Brightness is most evident and size is more readily perceived than form.

TRAINING METHODS

The work of Hoge and Stocking, (1912) indicates that punishment is more effective than reward as a motive for visual discrimination. In the present experiments it was found that, with the more difficult problems, punishment as a motive had serious disadvantages. With the dancing mouse Yerkes finds punishment to be more efficient than hunger. But unlike the dancing mouse, the adult albino rat is inactive and so a strong motive must be used to induce it to go through the discrimination box. Food furnishes practically the only available motive and must be used almost constantly if the time of reaction is to be kept within convenient limits.

When punishment is introduced in connection with food there is an immediate slowing of the reaction. As a general rule this is evidenced by a hesitation in leaving the starting compartment rather than in choosing one of the passages. The animals show a tendency to go through the discrimination compartment and passages in as few leaps as possible, frequently determining their direction before leaving the starting box.

The difficulty in regulating the severity of the punishment forms the chief objection to its use. The rats differ greatly in sensitivity to the current; No. 3 showed evidence of pain with a shock which the experimenter could not detect, while No. 2 gave no reaction to a current many times as strong. The same rat also differs in sensitivity at different times, and a single instance of too severe punishment is apt to lead to the formation of position habits which can be broken up only with the greatest difficulty. In a difficult problem, with long continued failure to discriminate, the animals become stubborn under punishment and may refuse to leave the starting compartment. For these reasons the use of punishment was almost entirely abandoned. In one case only, that of rat No. 6, was it retained in all the experiments. Her record is not greatly superior to that of the others, although in many ways she appears to be the most intelligent of the group.

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THE INTELLIGENCE OF EARTHWORMS

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From the Harvard Psychological Laboratory

Five figures

"But some degree of intelligence appears to be exhibited in this work [the plugging of the mouths of their burrows with various objects by earthworms],—a result which has surprised me more than anything else in regard to worms."[1] Thus wrote Charles Darwin as a result of his careful study of the habits of earthworms. Certain of his observations and the conclusion to which he felt himself forced have been discredited by the recent work of Miss Hanel.[2] Darwin, doubtless, was overliberal in his ascription of "mental qualities" to the worm, but Hanel certainly has proved herself extremely critical and parsimonious. In spite of the honest efforts of these excellent observers, and of many other biologists who have paid special attention to the behavior of earthworms, it must be admitted that we to-day know little concerning the possibilities of habit formation in these organisms.

The present investigation, taking its start from the work of Darwin, as critically repeated by Hanel, was planned for the purpose of (a) demonstrating the ability or inability of the earthworm to acquire direction-habits; (b) exhibiting the characteristics of such habits as might appear; (c) discovering external and internal factors important in connection with such habits; (d) determining the degree of permanency of habits; and (e) discovering the relation to the "brain" of such habits as appeared.

This paper is an introductory and preliminary account of an investigation which is still in progress. It is limited to a description of the general method employed and to a detailed account of the behavior of a single worm, No. 2, (*Allolobophora foetida*), which was under observation from October, 1911, until September, 1912. It is the writer's purpose to presen later a monographic account of his experiments with species of *Allolobophora* and *Lumbricus.*

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[1] Darwin, Charles. Formation of Vegetable Mould Through the Action of Worms. New York: D. Appleton and Company, 1898, p. 35.

[2] Hanel, Elise. Ein Beitrag zur "Psychologie" der Regenwürmer. Zeit. für allg. Physiol., 1904. Bd. 4, S. 244–58.

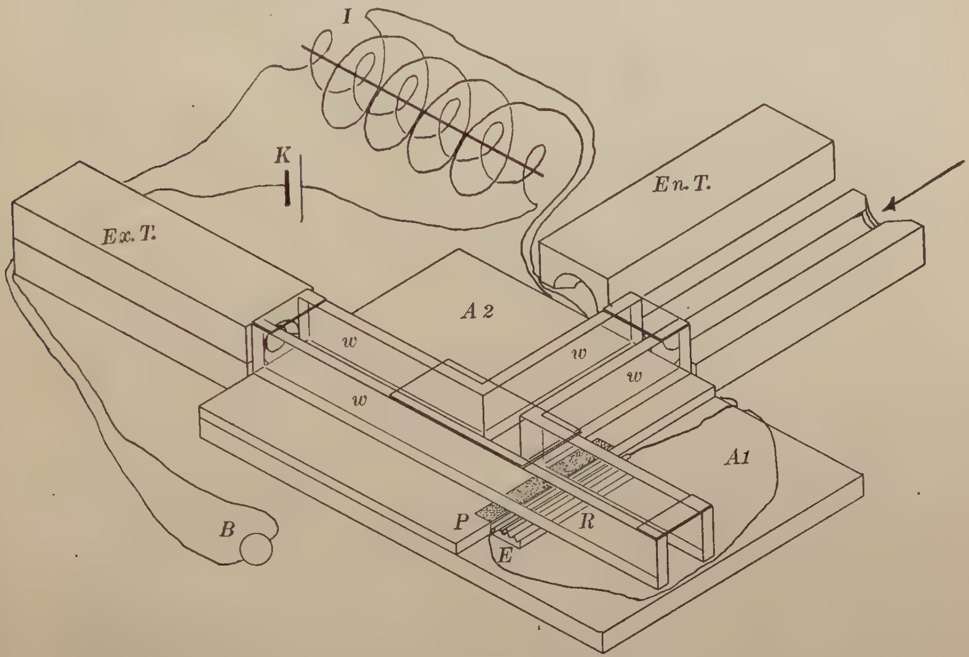

FIGURE 1. Perspective of T apparatus for study of habit formation in the earthworm. A 1, plate-glass base for parts of apparatus; A 2, layers of white blotting paper covering approximately two-thirds of A 1; w, w, w, w, plate-glass walls of T-shaped passage-way; En.T., wooden entrance tube, lined with moistened white blotting paper, from which worm enters passage-way, as indicated by arrow (the cover of the tube is shown removed); Ex.T., wooden exit tube in position for reception of worm as it emerges from open arm of glass T (in this case, the cover is in position); P, strip of sandpaper resting on A 2 and extending across passage-way; E, pieces of copper wire serving as electrodes, insulated and kept at fixed distance from one another by the corrugations of the strip of rubber, R; I, inductorium, wires from the secondary coil of which terminate in the electrodes at E; K, key in primary circuit of inductorium; B, dry cell.

In figure 1 is reproduced a perspective drawing of the apparatus used in the investigation. It consists of a T shaped labyrinth of plate glass, with runways 2 centimeters wide. The glass walls, w, are 2½ centimeters high and the distance from either entrance to the middle point of the unbroken wall is 12 centimeters. The walls are held together by four pieces of glass which are cemented to their upper surfaces with "cementium." The glass T rests upon a piece of plate glass two-thirds of which is covered, as is indicated in the figure, by layers of white blotting paper to the thickness of 5 millimeters The remainder of the base-plate is left uncovered in order that a piece of rubber, R, may be inserted under the T as insulation for two copper electrodes, E.

Wooden tubes which serve as artificial burrows appear at En.T. and Ex.T. The former may be designated the entrance tube and the latter the exit tube. The "tubes" are made by boring a 13 millimeter hole the length of a block of soft wood 14 by 4 by 4 centimeters. The block is then split. The ends of the hole are bevelled and sandpapered and the lower half is lined with white blotting paper.

A strip, 1 centimeter wide, of No. ½ sandpaper extends across one arm of the T, as shown at P, (figure 1); and just beyond the outer edge of the sandpaper, resting on the plate glass base, is the piece of corrugated rubber, R, in two of the grooves of which lie the copper electrodes, E.

In the early experiments with worm No. 2, a piece of glass carrying a strip of blotting paper which had been soaked in strong salt solution,[3] took the place of the rubber and the electrodes.

This apparatus was designed to test the ability of earthworms to "learn" to follow a simple path and to avoid an injurious chemical (or electrical) stimulus by reacting negatively to a peculiar tactual stimulus which regularly preceded the chemical. The experimenter had in mind two questions: First, can the worm profit by experience; second, can it "associate" the tactual stimulus with the chemical and acquire the habit of regularly responding to the sandpaper as tho it anticipated the effect of the salt.

In September, 1911, a number of manure worms were collected at Cambridge, Massachusetts, for this investigation. Those selected for use were kept in earthenware jars, 10 centimeters deep by 7.5 centimeters in diameter, in a moist mixture of earth and horse manure. Number 2, the subject of this report, was, from the first, an active, vigorous individual, which reacted well in the apparatus and evidently throve on the treatment afforded it. Between September, 1911, and September, 1912, it doubled its size.

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[3] The solution was made by dissolving 60 grams of c. p. sodium chloride in one liter of distilled water.

Each day, in preparation for the experiments with No. 2, the blotting paper upon which the glass T rested was soaked with tap water, as were also the paper linings of the entrance and exit tubes. The apparatus was then set with the stem of the T directed toward and perpendicular to a north window which was the sole source of illumination during experimentation. The strip of sandpaper now was properly placed beneath one arm of the T at 1 centimeter from the adjacent wall of the stem, and just beyond it, on the plate glass base, instead of on the blotting paper, a thin piece of glass supporting a strip of blotting paper soaked in salt solution was adjusted.[4]

When the apparatus was in readiness the experimenter removed the worm from its jar by inverting the latter over a dish and emptying the entire contents. Then with a fine camel's hair brush the worm was removed to a small dish of water, to wash off any adhering particles of earth. Thence it was carefully, but quickly, transferred to the lower half of the entrance tube and immediately covered with the upper half to protect it from the light.

A "trial" or "test" was given as follows: Having placed the entrance tube containing the worm at the base of the stem of the T, with the anterior end of the worm directed toward the T, the experimenter removed the cover of the tube, thus permitting the light from the window to drive the negatively phototactic worm into the T. If the light did not within a few seconds cause the subject to move forward, it was lightly stroked along the dorsum of the terminal segments with a moist camel's hair brush.

No. 2 usually started quickly, and especially in the later experiments, without being "touched."

The experimenter noted, by referring to a watch, the moment of uncovering the tube, and registered the beginning of the trip thru the T by starting a stop-watch the instant the head of the worm entered the stem of the T. He then observed minutely the behavior of the worm in the apparatus, recording as accurately as might be the path followed, the number of times the worm came into contact with the strip of sandpaper and the number of times it received the chemical (or electrical) stimulus.

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[4] In the later experiments with worm No. 2 the strip of rubber and the electrodes took the place of the apparatus for chemical stimulation.

The subject was permitted neither to retrace its course thru the stem of the T to the entrance tube, nor to escape by the arm containing the sandpaper.

The instant the "head" of the worm entered the exit tube the experimenter stopped the stop-watch and recorded the results of the trial.

For convenience, as well as accuracy, in the recording of data an outline of the apparatus, similar to that of figure 2, was cut in rubber and on the blank impressions produced with this stamp the observer recorded (a) the number of the "trial," (b) the hour, (c) the total time for the "trip," (d) the number of contacts with the sandpaper, (e) the number of chemical (or electrical) stimulations, and (f) the path followed. Supplementary notes concerning features of the behavior frequently were appended.

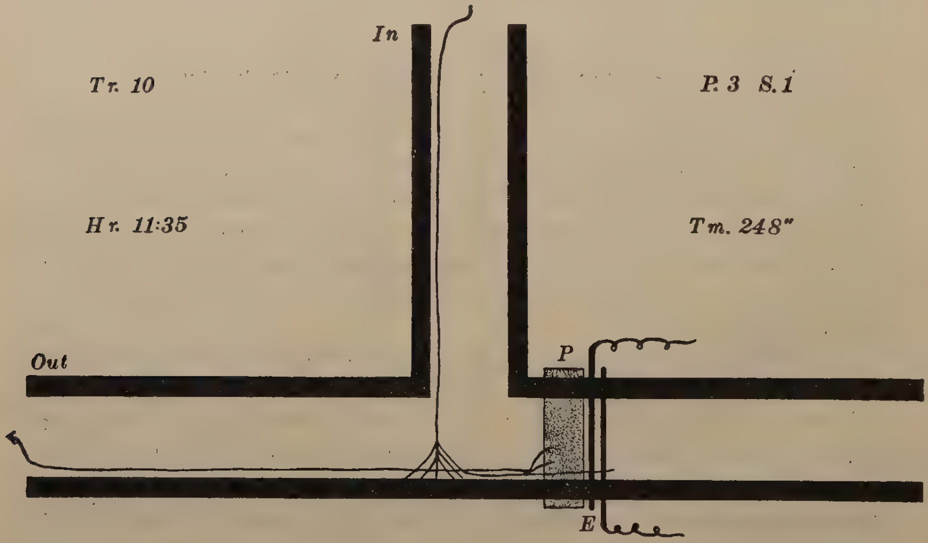

FIGURE 2. Ground plan of T, showing path followed by earthworm No. 2 in trial 10. (In this figure and the following one, fig. 3, a piece of blotting paper soaked in salt solution took the place of the electrodes at E.)

Experimentation with worm No. 2 was begun October 12, 1911. On that day it was given ten trials in the apparatus. An interval of about twenty minutes, gradually diminished to five in the later series, separated the trials.

For several weeks worms No. 2 and No. 1 were given trials alternately in order that they might obscure one another's mucous trails. From the first the sandpaper proved to be slightly repellent to No. 2. Consequently the chemical stimulus was received in only two of the first series of 10 trials. In accordance with chance, the worm turned as often to the right arm of the T as to the left arm.

Four days after the first series, on October 16, a second series yielded results strikingly similar to those of the first day, and as strikingly in contrast with those obtained on the third day.

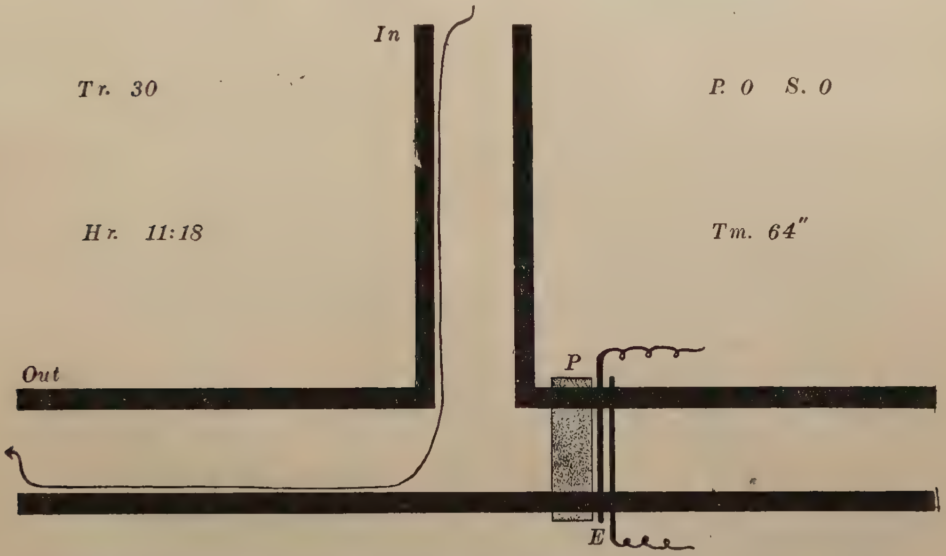

Figure 3. Diagram of T, showing path followed by earthworm No. 2 in trial 30.

The data for the first three series of trials are presented in table 1. In these results it is remarkable that, after only 20 experiences in the apparatus, No. 2 should have succeeded, on October 17, in passing thru the T from entrance tube to exit tube 10 times in succession without a mistake in the direction of turning and usually with directness.

In trial 21, the first on October 17, the worm followed the left wall of the stem of the T as far as the junction of the arms, then turned sharply to the right and passed directly into the exit tube. In trials 22 to 30 it, instead, followed the right wall of the stem, thus taking the shortest route to the exit tube (figure 3).

The route shown in figure 2 is typical of the early indirect journeys; that of figure 3, of the later direct trips.

As appears in table 1, the average time for the first 10 trips was 163″; for the second 10, 103.5″; for the third 10, 68.5″.

TABLE 1

Results of First Thirty Training Experiments with Worm No. 2

Date	Trial	Contacts with		Time
		Sandpaper	Salt	
Oct. 12	1	0	0	61″
“	2	2	0	84″
“	3	0	0	68″
“	4	0	0	85″
“	5	3	0	146″
“	6	2	0	173″
“	7	12	5	480″
“	8	0	0	133″
“	9	0	0	152″
“	10	3	1	248″
Average of ten trials		**2.2**	**.6**	**163″**
Oct. 16	11	1	1	126″
“	12	1	0	66″
“	13	1	0	71″
“	14	0	0	60″
“	15	3	1	159″
“	16	0	0	87″
“	17	2	1	180″
“	18	0	0	63″
“	19	0	0	114″
“	20	2	0	109″
Average of ten trials		**1**	**.3**	**103.5″**
Oct. 17	21	0	0	75″
“	22	0	0	109″
“	23	0	0	58″
“	24	0	0	46″
“	25	0	0	63″
“	26	0	0	61″
“	27	0	0	70″
“	28	0	0	56″
“	29	0	0	83″
“	30	0	0	64″
Average of ten trials		**0**	**0**	**68.5″**

These results strongly suggest to the student of animal behavior “tracking” or the directive influence of light. To the experimenter it seemed extremely improbable that the worm had acquired a perfect direction-habit as a result of only 20 trials in the T. For the present it must suffice to state that no satisfactory explanation for the correct series was revealed by check experiments. The worm apparently profited by experience with surprising quickness.

Between October 12 and November 6, as may be noted in the accompanying summary of experiments with No. 2, the worm was given 200 trials in series of 10 each. The results were variable. Thus we find that the perfect record for October 17 was followed by a record of contact with the sandpaper in three trials and with the salt in one trial on October 18, and that, in turn, by a perfect record on October 19.

Summary of Experiments with Worm No. 2

Trials	Dates	Direction of Turning	No. of Trials	Stimuli	Condition of Worm
1- 200	Oct. 12-Nov. 6, 1911	Right	10	Paper and salt	Normal
201- 400	Nov. 7-Nov. 17, 1911	"	20	" "	"
401- 510	Nov. 20-Nov. 30, 1911	"	10	" "	"
511- 645	Dec. 2, 1911-Jan. 25, 1912	"	5, 10, 15	" "	"
646- 710	Jan. 26-Feb. 13, 1912	"	5	" and elect.	"
711- 780	Feb. 15-Apr. 9, 1912	Left	5	" "	"
781- 860	Apr. 10-Apr. 30, 1912	Right	5, 10	" "	"
861- 920	May 2-June 7, 1912	"	5	" "	"Brainless"
921-1000	July 4-July 25, 1912	"	5	" "	"New Brain"

The training on the basis of 10 trials per day (with omission of experimentation occasionally) failed to establish a definitely predictable mode of response (perfectly dependable habit) in No. 2, so the number of trials per series was increased to 20, beginning on November 7. Thus the experimentation was continued until November 17, when No. 2 was given its four-hundredth trial. The results varied extremely from day to day. There appeared to be "good" and "bad" days. The data of tables 2 and 3 are offered in support of this statement.

Thus, November 8 (table 2) proved to be a "bad" day as compared with November 9. Likewise, November 10 proved to be unfavorable, whereas November 11 was favorable (table 3).

TABLE 2

RESULTS, WITH WORM NO. 2, INDICATIVE OF IRREGULARITY OF PERFORMANCE FROM DAY TO DAY. ("GOOD" AND "BAD" DAYS)

Date	Trial	Sand-paper	Salt	Time	Date	Trial	Sand-paper	Salt	Time
Nov. 8	221	0	0	110″	Nov. 9	241	4	3	204″
“	222	0	0	55″	“	242	0	0	60″
“	223	1	0	73″	“	243	0	0	59″
“	224	0	0	79″	“	244	0	0	65″
“	225	3	1	94″	“	245	2	0	104″
“	226	0	0	113″	“	246	0	0	81″
“	227	1	0	82″	“	247	0	0	68″
“	228	3	1	117″	“	248	0	0	65″
“	229	1	0	89″	“	249	0	0	51″
“	230	0	0	73″	“	250	0	0	59″
“	231	1	1	120″	“	251	0	0	62″
“	232	1	0	92″	“	252	0	0	65″
“	233	0	0	130″	“	253	0	0	58″
“	234	1	1	111″	“	254	0	0	80″
“	235	5	2	185″	“	255	2	0	81″
“	236	0	0	98″	“	256	2	0	122″
“	237	0	0	99″	“	257	2	0	100″
“	238	0	0	90″	“	258	0	0	64″
“	239	4	1	136″	“	259	0	0	157″
“	240	0	0	120″	“	260	1	0	73″
Av. of twenty trials		**1.05**	**.35**	**103.3″**	Av. of twenty trials		**.65**	**.15**	**83.9″**

TABLE 3

RESULTS, WITH WORM NO. 2, INDICATIVE OF IRREGULARITY OF PERFORMANCE FROM DAY TO DAY. ("GOOD" AND "BAD" DAYS)

Date	Trial	Sand-paper	Salt	Time	Date	Trial	Sand-paper	Salt	Time
Nov. 10	261	5	0	162″	Nov. 11	281	5	0	154″
“	262	0	0	133″	“	282	0	0	72″
“	263	0	0	97″	“	283	0	0	69″
“	264	0	0	86″	“	284	0	0	82″
“	265	0	0	81″	“	285	1	0	90″
“	266	0	0	105″	“	286	1	0	107″
“	267	0	0	87″	“	287	1	0	59″
“	268	3	1	138″	“	288	0	0	50″
“	269	0	0	100″	“	289	0	0	46″
“	270	0	0	105″	“	290	0	0	47″
“	271	2	1	119″	“	291	0	0	54″
“	272	3	2	138″	“	292	2	0	109″
“	273	7	3	239″	“	293	0	0	61″
“	274	0	0	98″	“	294	0	0	49″
“	275	0	0	154″	“	295	0	0	50″
“	276	2	0	77″	“	296	0	0	48″
“	277	0	0	73″	“	297	0	0	41″
“	278	3	1	110″	“	298	0	0	45″
“	279	2	0	107″	“	299	0	0	61″
“	280	0	0	240″	“	300	0	0	59″
Av. of twenty trials		**1.35**	**.4**	**122.4″**	Av. of twenty trials		**.5**	**0**	**67.6″**

All things considered, the results of the training by 20 trials per day were less satisfactory than those of the earlier training by 10 trials. The worm frequently exhibited fatigue before the completion of a 20-trial series. Concluding that he had been overworking his subject, the experimenter reduced the number of trials to 10 per day from November 20 to November 30,—trials 401–510.

TABLE 4

Results of First Trials in Daily Series Compared with Averages for the First Half of the Trials of the Daily Series

Trial	Sandpaper	Salt	Time	Trials	Sandpaper	Salt	Time
1	0	0	61″	1– 5	1.0	0	88.8″
11	1	1	126″	11– 15	1.2	.4	96.4″
21	0	0	75″	21– 25	0	0	70.2″
31	0	0	65″	31– 35	2.2	1.4	142.8″
41	0	0	82″	41– 45	0	0	64.8″
51	6	5	125″	51– 55	2.2	1.4	130.4″
61	1	0	120″	61– 65	5.0	2.8	165.8″
71	1	0	150″	71– 75	.8	0	122.0″
81	2	1	124″	81– 85	3.8	1.4	197.0″
91	0	0	84″	91– 95	.4	.2	104.6″
101	3	2	228″	101–105	1.2	.8	158.0″
111	3	2	167″	111–115	1.6	1.0	121.8″
121	7	6	283″	121–125	1.6	1.2	123.8″
131	1	1	149″	131–135	1.6	.8	119.0″
141	15	11	345″	141–145	3.2	2.4	137.2″
151	1	1	150″	151–155	1.4	.4	123.2″
161	14	10	345″	161–165	3.2	2.0	131.6″
171	0	0	103″	171–175	2.0	.4	113.6″
181	0	0	92″	181–185	.4	.2	84.0″
191	4	1	158″	191–195	2.0	.6	112.2″
201	3	0	89″	201–210	1.2	.3	88.2″
221	0	0	110″	221–230	.9	.2	88.5″
241	4	3	204″	241–250	.6	.3	81.6″
261	5	0	162″	261–270	.8	.1	109.4″
281	5	0	154″	281–290	.8	0	77.6″
301	7	2	222″	301–310	1.2	.4	95.3″
321	1	0	102″	321–330	1.4	.3	102.2″
341	0	0	62″	341–350	.7	.5	100.1″
361	8	0	169″	361–370	2.2	.1	98.3″
381	3	1	187″	381–390	1.5	.5	109.8″
401	4	2	289″	401–405	1.8	1.0	156.2″
411	0	0	58″	411–415	0	0	72.0″
421	1	0	113″	421–425	.6	.2	134.0″
431	4	2	279″	431–435	.8	.4	112.8″
441	0	0	104″	441–445	1.0	.4	101.0″
451	3	1	213″	451–455	.8	.2	110.8″
461	0	0	206″	461–465	.6	.2	154.2″
471	0	0	151″	471–475	.6	.6	172.4″
481	0	0	77″	481–485	0	0	73.2″
491	3	1	67″	491–495	1.2	.4	114.4″
Averages	**2.75**	**1.32**	**151.2″**	**Averages**	**1.34**	**.59**	**114.0″**

Table 4 presents, on the left, the results of the first trial in each daily series up to the five-hundredth trial, and, on the right, the averages of the data for the first half (5 or 10) of the trials of each daily series. It appears that more than twice as many contacts with sandpaper and salt were made in "first" trials as in the "first half" of the series. There is evidence of daily improvement in this comparison, but no proof of the acquisition of a habit which lasts from day to day.

The experimental procedure was further modified in the interval between December 2, 1911, and January 25, 1912,—trials 511 to 645—by the use of as few as five trials in a series, and by the frequent changing of the blotting paper under the T and the washing of the walls of the T in order that "tracking" should be rendered impossible.

The results demonstrated (a) the superiority of five trials per day over a greater number, and (b) the tendency of No. 2 to follow its own mucous path.

Repeatedly it happened that the worm after being permitted to make several direct trips thru the T, *without change of floor*, made mistakes, hesitated, and wandered as a result of the substitution of fresh blotting paper and the washing of the walls with tap water. But like the other features of the behavior of the worm, the following of the mucous trail laid down in the previous trip is not constant. In many instances the path is wholly disregarded. Only exceptionally, therefore, could a "perfect" series result from the "tracking" tendency. Moreover, since no systematic study of this tendency was made previous to the five-hundredth trial, it is not certain that No. 2 did not acquire its ability to follow its mucous trail. Of chief importance in the present connection is the fact that "tracking" does not suffice to account for the "perfect" series obtained.

On January 26 an important improvement in the technique of the experiment was made by the substituting of the electrical stimulus for the chemical. The salt solution had proved unsatisfactory because each time the worm came into contact with it a certain amount was converged to the adjacent blotting paper. The electrical stimulus proved to be cleaner, more controllable and therefore preferable.

The electrical stimulus consisted of the induced current from a Porter inductorium, with secondary set at 6-7 on the scale, in circuit with a No. 6 Columbia dry battery.

From January 26, 1912, till February 13,—trials 646 to 710—

series of five trials each were given. Only exceptionally did the worm receive the shock in other than the first trial of a series, and in several instances, the series were almost perfect.

At this point in the experimentation is was decided to attempt to break the habit of escaping from the T by the right arm and to substitute for it a habit of escaping by the other arm. Between February 15 and April 9,—trials 711 to 780—five trials per day were given with the sandpaper and electrodes in the right arm, instead of in the left, and with the exit tube at the end of the left arm.

Under these conditions the worm persistently turned to the right, in accordance with its previous training. So strong was this tendency that in the consecutive series of April 6, 7 and 9 not a single correct trial appeared (table 5, left side).

TABLE 5

Results of Attempt to Break up Habit of Turning to Right in T. and Establish the Habit of Turning to the Left

	Turning to Left			
Date	Trial	Sand-paper	Shock	Time
April 5	761	4	1	200″
"	762	0	0	53″
"	763	5	2	134″
"	764	4	2	260″
"	765	0	0	119″
Av. of five trials		**2.6**	**1.0**	**153.2″**
April 6	766	3	1	248″
"	767	6	3	193″
"	768	3	1	65″
"	769	2	1	107″
"	770	2	1	65″
Av. of five trials		**3.2**	**1.4**	**135.6″**
April 7	771	3	1	149″
"	772	3	3	172″
"	773	2	1	170″
"	774	2	3	145″
"	775	3	1	92″
Av. of five trials		**2.6**	**1.8**	**145.6″**
April 9	776	5	2	173″
"	777	6	1	490″
"	778	4	2	189″
"	779	3	1	151″
"	780	2	1	111″
Av. of five trials		**4.0**	**1.4**	**222.8″**

	Turning to Right			
Date	Trial	Sand-paper	Shock	Time
April 10	781	0	0	31″
"	782	1	1	67″
"	783	0	0	40″
"	784	0	0	58″
"	785	0	0	30″
"	786	0	0	39″
"	787	0	0	42″
"	788	0	0	44″
"	789	0	0	148″
"	790	0	0	54″
Av. of ten trials		**.1**	**.1**	**55.3″**
April 11	791	0	0	130″
"	792	0	0	54″
"	793	0	0	45″
"	794	0	0	57″
"	795	0	0	45″
Av. of five trials		**0**	**0**	**66.2″**
April 12	796	0	0	97″
"	797	0	0	28″
"	798	0	0	51″
"	799	0	0	36″
"	800	0	0	65″
Av. of five trials		**0**	**0**	**55.4″**

After 70 trials, this attempt to break the direction-habit was given up because of the risk of injury to the subject from frequent electrical stimulation.

Beginning with April 10, the original conditions of training were reestablished, and, with few exceptions, the correct course was taken in trials 781 to 860. Several series were perfect.

The contrast between the features of behavior under the differing conditions of training—with apparatus arranged for escape by the left arm, and for escape by the right arm—is indicated in table 5. With the new condition of training there were few successful trials, with the old there were few failures. With the new, the worm wandered, baffled; with the old it escaped directly.

In the three weeks of training, April 10-30, the tactual and electrical stimuli were seldom received. The worm usually followed the right wall of the stem of the T from the entrance tube and turned to the right with a fair degree of directness upon coming in contact with the "common" wall of the arms.

The results of trials 781 to 860 were more clearly indicative of a definite direction-habit than any previously obtained. Table 6 presents a few typical series. Excellent evidences of the association of tactual with electrical sensations also appeared.

TABLE 6

Results Indicative of Perfection of Habit Before Amputation of First Five Segments

Date	Trial	Sand-paper	Salt	Time	Date	Trial	Sand-paper	Salt	Time
April 23	801	0	0	52″	April 25	821	0	0	141″
"	802	0	0	76″	"	822	0	0	30″
"	803	0	0	45″	"	823	0	0	58″
"	804	0	0	36″	"	824	0	0	37″
"	805	0	0	53″	"	825	0	0	38″
"	806	0	0	40″	"	826	0	0	28″
"	807	0	0	73″	"	827	0	0	35″
"	808	2	0	78″	"	828	0	0	41″
"	809	0	0	49″	"	829	0	0	45″
"	810	3	0	240″	"	830	0	0	48″
Av. of ten trials		**.5**	**0**	**74.2″**	Av. of ten trials		**0**	**0**	**50.1″**
April 24	811	0	0	49″	April 26	831	0	0	61″
"	812	3	0	240″	"	832	3	0	63″
"	813	0	0	30″	"	833	0	0	52″
"	814	0	0	24″	"	834	0	0	49″
"	815	0	0	21″	"	835	0	0	43″
"	816	0	0	40″	"	836	0	0	54″
"	817	0	0	47″	"	837	0	0	72″
"	818	0	0	39″	"	838	0	0	43″
"	819	0	0	62″	"	839	0	0	89″
"	820	0	0	39″	"	840	0	0	281″
Av. of ten trials		**.3**	**0**	**59.1″**	Av. of ten trials		**.3**	**0**	**80.7″**

In view of this positive result of the training, it was deemed worth while to proceed with the next step in the investigation,—namely, amputation of the anterior segments, with the "brain," in order that the relation of the habit to the "brain" might be studied.

At 5 p. m. on April 30 the prostomium, the first four segments and about half of the fifth were amputated with a sharp pair of scissors. The worm was in splendid physical condition at the time. It reacted markedly for a few seconds but not violently to the mutilation. Immediately after the operation it was placed between layers of moist filter paper in a jar. Thus it was left over night.

When uncovered and exposed to the light at 10 a. m., May 1, it immediately began to crawl forward. It seemed very sensitive to photic and tactual stimuli, and it moved freely both forward and backward. The wound, which had closed, appeared to be in excellent condition. After the examination, the filter paper was removed, the jar washed and the worm replaced between layers of fresh paper.

So wholly satisfactory was the condition of the subject on May 2, 40 hours after the operation, that it seemed desirable to resume experimentation.

With the apparatus arranged precisely as in the previous series of trials, (April 30) the worm was permitted to enter the T. It moved forward, more slowly and continuously than before the operation, into the middle of the stem. Thence it proceeded by a path which is reproduced in figure 4. Having reached the "common" wall of the arms, it turned to the left and five times pushed forward to the sandpaper, each time withdrawing upon contact. As it searched with the cut end, for a way of escape, the "tail" became active and moved about as if "feeling" for a path. Shortly a turn toward the right was made and, with repeated attempts to crawl up the glass wall, the worm approached the exit tube. The instant the "head" end came in contact with the moist lining of the tube the worm pushed forward as in "recognition" of the retreat.

The trial which has been described was given at 9:16 a. m., and at 9:30 a second trial resulted in a direct trip thru the T. The note-book record reads: "Entered quickly and directly. With 'head' end raised 3-4 millimeters from the floor and in contact with the right wall of stem it rapidly moved forward to junction of arms. It then veered sharply toward the exit tube. On reaching the "common" wall it stopped and felt about for a few seconds, making no attempt to reach up or to swing from side to side. In this the behavior is unusual. After a few seconds it started for the tube, gradually ascending the wall of the arm as it approached the exit." The trip was a quick one, in which only the unusual features have been mentioned.

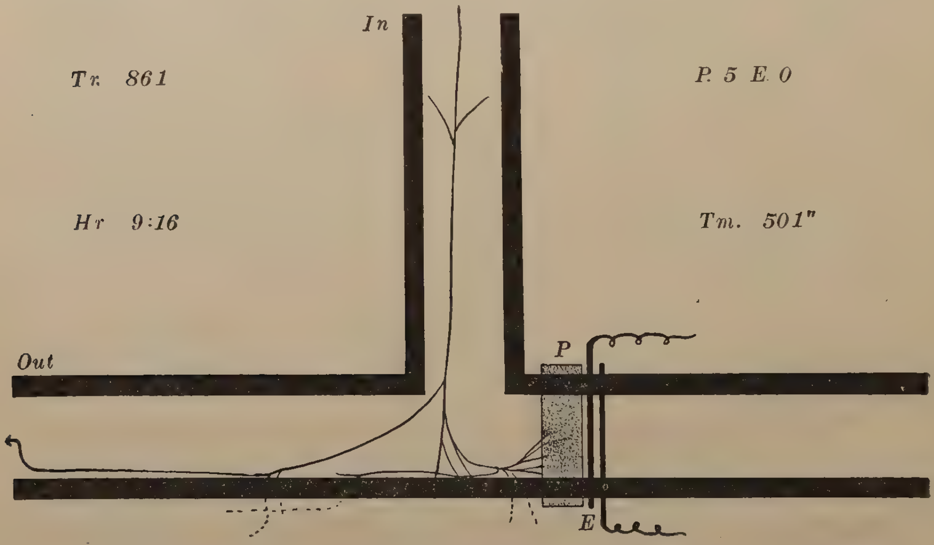

FIGURE 4. Diagram of T, showing path followed by earthworm No. 2 in first trial after removal of the brain.

The third trial, at 9:52, and the fourth, at 10:03, yielded results similar to that of the second. But in the fifth, 10:15, the path for which appears in figure 5, the worm followed the left wall of the stem instead of the right, felt about at the point of contact with the "common" wall, finally turned toward the exit, and, with frequent attempts to crawl over the wall of the arm, approached, reached, and quickly entered the tube.

Following this first series of trials with the "brainless" worm, at intervals of from two to seven days, additional series of five trials each were given until June 7. The general results appear in table 7.

The most important features of the behavior during this period of rapid regeneration of the "head" will now be described.

In trial 866 (first of May 4) the worm chose the wrong arm. Unmindful of the sandpaper, it pushed forward until the cut end touched the first electrode, whereupon it suddenly drew back and turned toward the exit tube. That this reaction was due to anticipation of the electrical stimulus is possible, but quite as likely it was due to a chemical stimulus from the copper electrode.

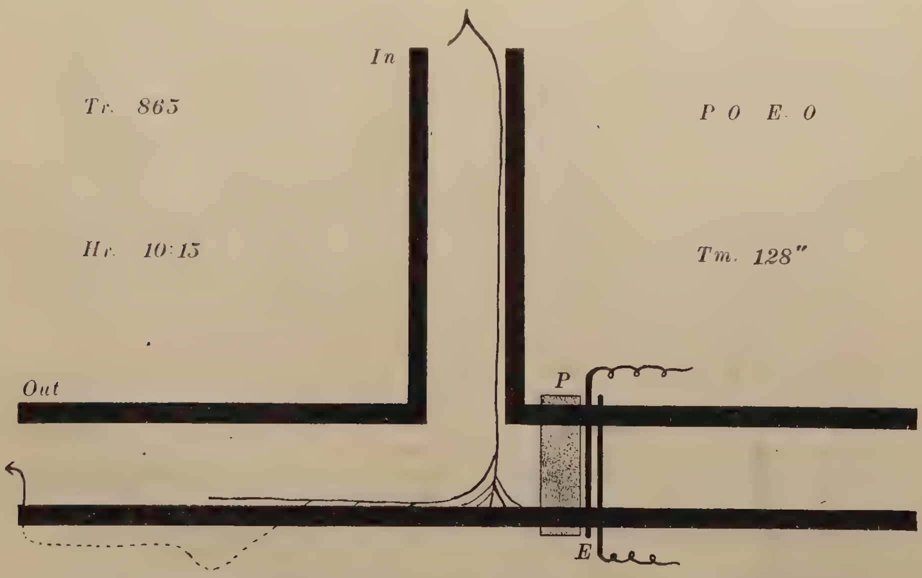

Figure 5. Diagram of T, showing path followed by earthworm No. 2 in fifth trial after removal of brain.

In the very next trial (867) the worm turned toward the right as it left the entrance tube, and, coming to the wall of the stem, pushed vigorously against it, while continuing to move forward, as if trying to round the corner of the stem and right arm before reaching it. To the experimenter, it looked as tho it anticipated the turn and miscalculated the distance by just about the length of the amputated segments. As soon as it reached the angle of stem and arm, it veered sharply to the right, while moving toward the "common" wall. Upon reaching the latter it pushed against it, stopped for a moment, then turned to the right again and moved directly and rapidly into the tube.

TABLE 7

Results of Experiments After Removal of Brain on April 30

Date	Trial	Sand-paper	Shock	Time
May 2	861	5	0	501″
"	862	0	0	91″
"	863	0	0	82″
"	864	0	0	102″
"	865	0	0	128″
Av. of five trials		**1**	**0**	**180.8″**
May 4	866	2	0	403″
"	867	0	0	84″
"	868	0	0	201″
"	869	0	0	271″
"	870	1	0	310″
Av. of five trials		**.6**	**0**	**253.8″**
May 6	871	2	1	505″
"	872	0	0	74″
"	873	1	0	441″
"	874	0	0	130″
"	875	3	2	644″
Av. of five trials		**1.2**	**.6**	**358.8″**
May 9	876	0	0	149″
"	877	0	0	126″
"	878	0	0	465″
"	879	0	0	155″
"	880	0	0	231″
Av. of five trials		**0**	**0**	**225.2″**
May 13	891	0	0	273″
"	892	0	0	231″
"	893	0	0	107″
"	894	0	0	330″
"	895	0	0	386″
Av. of five trials		**0**	**0**	**265.4″**
May 21	896	1	0	327″
"	897	0	0	73″
"	898	0	0	55″
"	899	0	0	76″
"	900	1	0	117″
Av. of five trials		**.4**	**0**	**129.6″**
May 28	901	3	1	300″
"	902	0	0	72″
"	903	0	0	91″
"	904	0	0	48″
"	905	0	0	53″
Av. of five trials		**.6**	**2**	**112.8″**
May 29	906	4	2	355″
"	907	0	0	64″
"	908	0	0	57″
"	909	0	0	39″
"	910	0	0	60″
Av. of five trials		**.8**	**.4**	**115″**
June 6	911	0	0	430″
"	912	2	0	185″
"	913	0	0	77″
"	914	0	0	65″
"	915	0	0	54″
Av. of five trials		**.4**	**0**	**162.2″**
June 7	916	4	1	442″
"	917	0	0	52″
"	918	0	0	47″
"	919	0	0	45″
"	920	0	0	60″
Av. of five trials		**.8**	**.2**	**129.2″**

Trial 871, given at 10:45 on May 6, five and one-half days after the operation exhibited precisely the kind of behavior that the experimenter had expected of the "brainless" worm. The subject, with its conspicuous "plug" of regenerating tissue, moved forward readily, but reversed whenever an obstacle was encountered. It wandered about a great deal, as if lost. Finally, it touched the electrodes, received the shock, and reacted violently by "springing back" to the middle of the T. It then reversed and *backed* into the exit tube. The posterior end seemed to "recognize" the tube. Thruout this trial the "tail" manifested unusual initiative.

The worm lost itself in the third, and again in the fifth trial. Concerning the latter the note-book affords the following comments. "The behavior contrasts markedly with that of previous trials. There is little initiative for forward movement. Th[illegible]ally had to be driven into the exit tube."

May 6 was evidently a "bad" day, due probably to an unfavorable physical condition.

The worm did not burrow in earth for three weeks after the operation. On May 21, it was found completely covered with loose earth. The regenerated portion at this time appeared clearly segmented and complete, but not yet as large as were the amputated segments.

The tendency to climb the walls of the T which was so conspicuous a feature of the behavior immediately after the operation gradually disappeared as the process of regeneration progressed. Within three weeks, the worm pushed along close to the floor of the apparatus, as it did before the operation.

For the first time, the worm was found naturally embedded in a well-formed earth-burrow on May 28. The regenerated segments were nearly full-size and differed from the others only in their lighter color. On this date the worm wandered more than formerly. It exhibited increased initiative and a proportional increase in mistakes. Whereas immediately after the operation the subject was automatic in its reaction to the apparatus, it now exhibited varied response.

From June 7 until July 4, a period of four weeks, the subject was permitted to rest in order that the persistence of the habit might be tested.

Previously the effect of rest had been observed by the suspension of training from December 19 until January 8, three weeks, with the result that the trials immediately after the "rest" were better than those before it. No indication of loss of the habit by the normal worm within three weeks appeared.

From the outset the trials with the regenerated worm, following upon a four-week's interval of rest, were marked by mistakes. On July 4 not a single trial was correct; on July 5, only two out of five; on July 8, only one of five (table 8).

TABLE 8

Results of Experiments After Complete Regeneration and One Month Without Trials in T

Operation, April 30; *Last Trial, June* 7

Date	Trial	Sand-paper	Shock	Time
July 4	921	1	1	268″
"	922	2	1	178″
"	923	5	1	755″
"	924	3	1	461″
"	925	9	4	987″
Av. of five trials		**4.**	**1.6**	**529.8″**
July 5	926	0	0	113″
"	927	0	0	54″
"	928	3	0	68″
"	929	3	2	275″
"	930	5	1	668″
Av. of five trials		**2.2**	**.6**	**235.6″**
July 8	931	15	13	732″
"	932	5	8	149″
"	933	0	0	117″
"	934	3	4	485″
"	935	2	1	605″
Av. of five trials		**5.**	**5.2**	**417.6″**
July 9	936	1	1	184″
"	937	4	2	264″
"	938	3	0	49″
"	939	0	0	43″
"	940	3	1	169″
Av. of five trials		**2.2**	**.8**	**141.8″**
July 10	941	2	0	79″
"	942	0	0	33″
"	943	4	1	106″
"	944	0	0	58″
"	945	3	2	213″
Av. of five trials		**1.8**	**.6**	**97.8″**
July 16	961	0	0	38″
"	962	0	0	44″
"	963	1	1	65″
"	964	0	0	46″
"	965	0	0	53″
Av. of five trials		**.2**	**.2**	**49.2″**
July 17	966	3	0	71″
"	967	0	0	35″
"	968	0	0	50″
"	969	1	0	58″
"	970	2	0	115″
Av. of five trials		**1.2**	**0**	**65.8″**
July 18	971	9	2	257″
"	972	0	0	72″
"	973	0	0	56″
"	974	0	0	57″
"	975	0	0	46″
Av. of five trials		**1.8**	**.4**	**97.6″**
July 19	976	1	0	241″
"	977	0	0	43″
"	978	5	2	275″
"	979	1	1	94″
"	980	4	2	216″
Av. of five trials		**2.2**	**1.**	**173.8″**
July 22	981	7	0	217″
"	982	0	0	25″
"	983	0	0	32″
"	984	0	0	42″
"	985	0	0	68″
Av. of five trials		**1.4**	**0**	**76.8″**

Apparently the habit had degenerated. This may be attributed to (a) period of inactivity; (b) regeneration of ganglia and resumption of normal functioning bringing in new modes of reaction; or (c) a combination of these factors.

To the writer it seems probable that the interval of rest witnessed the birth of a new worm thru the regeneration of the nervous system. The habitual reaction which the "brainless" individual had exhibited now gave place to new modes of behavior initiated by the new "brain" cells.

Since it had been demonstrated that the previously acquired direction-habit had disappeared from the regenerated worm after an interval of four weeks' rest, training was instituted for the purpose of re-establishing the habit.

Gradually the behavior changed; the number of mistakes diminished and the trips became more direct. The data of table 8 indicate the nature and rapidity of the change which occurred between July 4 and July 22. Only one mistake was made in each of the series on July 16, 18, and 22.

It would seem therefore that worm No. 2, having (1) acquired a certain direction-habit as the result of systematic training, (2) lost the habit by reason of the regeneration of the ganglia of its anterior segments, and (3) exhibited a tendency to turn in the opposite direction to that demanded in the memory tests, which tendency (4) later was overcome by systematic training and gave place to a definite direction-habit.

SUMMARY

1. The manure worm *Allolobophora foetida,* is capable of acquiring certain modes of reaction which involve a definite direction of movement and the association of two stimuli.

2. The habit appears as a result of from 20 to 100 experiences. It is inconstant even when perfectly formed, varying markedly with the physiological condition of the worm ("good" and "bad" days) and with imperfectly controlled external conditions (temperature, moisture, light, etc.).

3. The results of training on the basis of five trials a day, or every other day, are more satisfactory than those obtained with 10, 15 or 20 trials a day.

4. There is a tendency to "track" (follow the slime or mucous path) if the apparatus is not thoroly cleansed between trials, but this tendency is not sufficiently strong or constant to yield perfect series.

5. Evidences of the effects of experience appear thruout the systematic training in (a) the increased readiness to enter the apparatus and to desert it for the exit tube; (b) the evident "recognition" of the exit tube; (c) the gradually increasing avoidance of the sandpaper, which was meant to serve as a warning against the electrical stimulus; (d) the acquired tendency to avoid contact with the electrodes; (e) the disappearance

of the tendency to attempt to retrace the course thru the stem of the T; (f) the similar disappearance of the tendency to turn back after progressing well toward the exit tube. These several bits of evidence, combined with the still more obvious increase in the number of correct or shortest trips, justify the conclusion that the worm is capable of profiting by experience in a simple maze.

6. The correct performance of a thoroly ingrained habitual act, of the kind studied in this investigation, is not dependent upon the "brain" (portions of the nervous system carried by the five anterior segments), since the worm reacts appropriately within a few hours after its removal.

7. As the brain regenerates, the worm exhibits increased initiative, its behavior becomes less automatic, more variable.

8. Within four weeks after the operation the regenerated segments appear superficially complete and the worm naturally burrows in a mixture of earth and manure.

9. Two months after the removal of the "brain," during the last four weeks of which period no training was given, the habit had completely disappeared from worm No. 2, the subject to whose responses this paper is devoted, and in its place there appeared a tendency to turn in the opposite direction to that demanded in the training.

10. Systematic training for two weeks resulted in the partial re-acquisition of the original direction-habit.

11. The various facts recorded in this investigation indicate that the removal and the regeneration of the first five segments resulted in the development of a worm strikingly different in behavior from the original worm, No. 2.

All of the statements of this paper are based upon the behavior of a single worm, and all of the conclusions are subject to modification in the light of results which are being obtained with other individuals. It has seemed to the writer desirable to present this individual study while the facts are fresh in his mind and the details of the behavior may be used to advantage.

The writer desires to acknowledge his indebtedness to his friend and colleague, Professor Herbert W. Rand, for valuable advice and aid in the investigation.

REACTIONS OF THE MASON WASP, *TRYPOXYLON ALBOTARSUS,* TO LIGHT

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Several organ-pipe shaped cells of this species of mason wasp were placed in an insect cage 16 inches high, 12 inches wide and 12 inches deep. The bottom and the framework of this cage were constructed of wood, the sides and top were covered with fine wire gauze. When not under observation, the cage containing the insects was kept in a room with an average temperature of 70 degrees, and in which the temperature never fell below 60 degrees. The groups of cells [1] were placed close together on the floor of the cage. For food a watch-glass of honey was placed in the cage. To supply the wasps with water, under normal conditions, a cloth syphon led from a bent-neck bottle of water to a Minot watch-glass of mud.

DESCRIPTION OF EXPERIMENTS

SERIES I

In this series of experiments direct sunlight was used as a stimulus. The cage containing the wasps was placed in an east window in such a position that all parts of the cage not shaded by the framework were bathed in the direct rays of the sun. The shadows ranged from two to two and a half inches in width.

While in the sunlight the wasps, as a rule, were quite active, but the behavior was varied. Many climbed the sides of the enclosure; a few flew, at random, about the cage or hovered before one of the sides; occasionally one would sip the honey or drink the water. When wasps in walking upwards through the sunlight arrived at the shadow produced by the upper border of that side of the cage they would usually pass on into the shadow; occasionally one would turn half around and move along the line that separated the lighted from the shaded portion; but in no case did the wasp drop backwards or turn through an angle of 180 degrees.

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[1] For the majority of these nests I must thank my friend Mr. Phil Rau of this city.

Two experiments were performed, one on the seventh and the other on the tenth of June, 1911. In each experiment, at intervals, the position of each wasp was noted. The results of those observations are recorded in the following two tables.

In each of the tables of this article, the number at the top of a column indicates the time when the observation was made. "Li." stands for "In the light," and "Sh." means "In the shadow."

Experiment 1, June 7th, 12 wasps involved.

Wasps resting on or hovering near the	8:30		8:40	
	Li.	Sh.	Li.	Sh.
east side of the cage	5	0	5	2
west side of the cage	0	1	0	0
roof of the cage	0	0	0	0
floor of the cage	2	3	0	2
other two sides	0	1	0	3
Total	7	5	5	7

Experiment 2, June 10th, a. m., from 18 to 28 wasps involved.[2]

Wasp resting on or hovering near	10:30		10:35		10:40		10:45		11:09		11:15		11:30	
	Li.	Sh.	Li.	Sh.	Li.	Sh.	Li.	Sh.	Li.	Sh.	Li.	Sh.	Li.	Sh.
east side of cage	15	3	10	2	8	3	0	4	1	5	6	3	5	3
west side of cage	0	1	0	0	0	1	0	3	0	5	0	5	0	9
roof of the cage	0	0	1	0	0	0	1	0	2	1	3	0	2	0
floor of the cage	5	0	3	2	1	0	1	1	0	4	0	3	1	1
other two sides	0	4	0	5	0	6	0	8	0	6	0	7	0	6
Total	20	7	14	9	9	10	2	16	3	21	9	18	9	19

SERIES II

In this series the stimulus was direct sunlight. The general arrangement was the same as in series I; but an opaque screen nine inches long and six wide was placed over some portion of the east side of the cage.

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[2] Wasps resting in or under the mud-cells were not counted. Since the number of wasps so situated varied from time to time, the number of wasps in the experiment was not uniform.

The wasps exhibited all of the kinds of behavior mentioned under series I, and, in addition, one was noticed working in the mud, but it did not attempt to construct a nest; and a few of the wasps climbing up through the sunlight were noticed to drop backwards as soon as they reached the shadow.

The following tables record the positions of the wasps at the times they were observed.

Experiment 3, June 7th, 12 wasps involved. Opaque screen covering the upper portion of the east wall of the cage.

Wasp resting on or hovering near the	Li.	Sh.
east side of the cage	3	5
west side of the cage	0	0
roof of the cage	0	0
floor of the cage	0	3
other two sides of the cage	0	1
Total	3	9

Experiment 4, June 8th, 1911, in the forenoon, 14 to 18 wasps involved. Opaque screen arranged across the middle portion of the east side of the cage so as to leave uncovered two inches above it and three below.

Wasps resting on or hovering near	9:37		9:45		10:00		10:05		11:10	
	Li.	Sh.	Li.	Sh.	Li.	Sh.	Li.	Sh.	Li.	Sh.
east side of the cage	3	2	4	3	2	3	6	2	7	2
west side of the cage	0	1	0	0	0	0	0	2	0	3
roof of the cage	0	0	0	0	0	0	0	0	0	0
floor of the cage	5	1	6	0	5	2	4	1	2	3
other two sides of the cage	0	2	0	2	0	2	0	3	0	1
Total	8	6	10	5	7	7	10	8	9	9

SERIES III

In this series of experiments, the cage containing the wasps was placed in a room of twilight brightness and a pyramid of white light from an electric projecting lantern passed through it at intervals. A water cell was used to filter out the majority of the heat rays. On the lantern side of the cage this gave a lighted patch seven inches wide and six high and on the remote side of the cage a similar patch 10 inches wide and eight high. A portion of the roof was also lighted.

No matter how actively the wasps might be flying or walking, when the light from the lantern was shut off they almost immediately became inactive. When the light was turned on, those wasps upon which it impinged immediately became active. Some walked and others flew at random about the cage. At intervals those flying would alight upon some portion of the cage. The positions of the wasps at stated intervals is given in the following table.

Experiment 5, June 14th, 1911, 16 to 25 wasps involved.

Wasps resting on or hovering near the	Lantern light shining						Lantern light turned off					
	11:25		11:44		12:45		11:30		11:35		1:14	
	Li.	Sh.	Li.	Sh.	Li.	Sh.	Li.	Sh.	Li.	Sh.	Li.	Sh.
lantern side of the cage	2	3	4	3	1	6	0	3	0	2	0	8
remote side of the cage	3	0	2	1	0	0	0	1	0	1	0	0
roof of the cage	2	3	1	4	0	3	0	4	0	1	0	3
floor of the cage	0	2	0	2	0	1	0	0	0	0	0	1
other two sides of cage	0	3	0	8	0	8	0	8	0	12	0	5
Total	7	11	7	18	1	18	0	16	0	16	0	17

SERIES IV

In this series of experiments the cage containing the wasps was placed in a room of twilight darkness and, at intervals, pyramids of colored light were projected through the cage, by means of an electric lantern. The sizes and distribution of the light patches were the same as in series III.

Experiment 6. After a beam of white light had been passing through the cage for seven minutes, at 1:22 p. m., a piece of cobalt glass was placed before the lens of the lantern.

The wasps that had been flying actively about the cage suddenly became inactive.

Experiment 7. At 1:37 p. m. a pyramid of white light was passed through the cage used in experiment 6.

A 1:40 p. m. a wasp began to fly and in about a minute several were flying about at random.

Experiment 8. At 1:45 p. m. the cobalt glass was placed before the lens.

By 2 o'clock all of the wasps were quietly resting upon some portion of the cage.

Experiment 9. At 2:03 p. m. the cobalt glass was removed, permitting the white light to pass through the cage.

At 2:04 p. m. a wasp began to fly and in less than two minutes four were on the wing.

Experiment 10. At 2:12 the piece of cobalt glass was placed in front of the lens.

Almost immediately the wasps became quiet. A little later one flew a short distance and then settled down. At 2:15 p. m. two were walking about, but none was on the wing.

Experiment 11. At 11:25 a. m., after the cage had been in twilight darkness for several hours and the wasps were resting upon parts of the cage, a pyramid of orange light was passed through the cage.

Immediately the wasps began flying at random about the cage and hovering before the sides; but, at 11:29 a. m., all had become quiet again.

Experiment 12. At 11:30 a. m. the light was turned out.

Experiment 12. At 11:46 a. m., a pyramid of orange light was passed through the cage.

At first there was practically no reaction. Seven wasps were resting on the sides of the cage with their heads directed upwards, one with its head directed downwards and seven with their heads directed sidewise. Three wasps were resting on the floor of the cage, and one wasp was cleaning its head, wings and abdomen. At 11:50 a. m. one began to fly and one was making a humming noise. In less than a minute after that several were flying at random about the cage, and others were crawling up the sides of it. At 11:55 a. m. all were quiet again, but at 11:56 several were on the wing.

Experiment 13. The light was turned off at 11:58 a. m.

Immediately all became quiet.

Experiment 14. At 12:00 m. a pyramid of ruby light was passed through the cage.

Immediately the wasps became active. Some walked about in an excited manner, others made random flights about the cage and yet others hovered before the sides. On alighting from their flight they would stop in both light and shadow. At 12:03 p. m. two were roaming afoot, the majority were restless, but none were flying.

Experiment 15. At 12:14 the light was turned out.

Soon all the wasps became quiet.

Experiment 16. At 12:16 p. m. a pyramid of ruby light was passed through the cage.

Up to 12:25 p. m., a lapse of nine minutes, all of the wasps remained quiet.

Experiment 17. At 12:25 p. m. a pyramid of white light was projected through the cage.

The light impinged on four wasps. At 12:27 a wasp resting on the lighted patch on the ceiling began to walk about through both light and shadow. At 12:28 p. m. several were making random flights about the cage or hovering before the sides. Two minutes later nine were on the wing.

Experiment 18. At 12:30 p. m. a pyramid of ruby light was passed through the cage.

Immediately the wasps became quiet. At 12:32 p. m. a few walked about and one flew from the top of a mud cell, across the ruby light, to the opposite side of the cage. At 12:38 p. m. all were quiet again.

Experiment 19. At 12:39 p. m. a pyramid of white light was passed through the cage.

In less than a minute five were flying, at random, about the cage.

Experiment 20. A pyramid of blue light was passed through the cage.

The wasps continued to fly.

Experiment 21. At 12:46 p. m. a beam of ruby light was projected through the cage.

Soon all of the wasps became quiet.

Experiment 22. At 12:48 p. m. a pyramid of blue light was passed through the cage.

At once one began to hum; and, in less than a minute, two were on the wing.

Experiment 23. At 12:51 p. m. the light was put out.

The flying ceased at once, a few wasps continued to walk about the cage.

DISCUSSION OF THE EXPERIMENTS AND CONCLUSIONS

The experiments which supplied the data for this paper extended over a period of three weeks; and each day, except Sundays, from two to four sets of experiments were performed. Naturally there were many repetitions of experiments and responses, and many slight modifications of each. These numerous experiments were necessary to secure the data for an impartial analysis of the behavior. To record the details of all of the experiments would be an unfruitful tax upon the patience of the reader; hence only a few sample experiments have been recorded in the section above. The following discussion, however, is based upon all of the experiments that were performed.

Feeding Instincts. Evidently *Trypoxylon albotarsus* is able to instinctively[3] feed or drink from liquids without getting into them. This is evidenced by the manner in which the wasps responded to honey placed in Minot watch-glasses. Almost invariably, whether it was a first visit or a subsequent one, the wasp mounted or alighted on the rim of the watch-glass, fed upon the honey, backed out, made a short flight of orientation, and then flew away. Sometimes the wasp would rest one of its fore feet upon the honey; but more often it would not. Occasionally the flight of orientation was omitted. Only once was a wasp noticed to get smeared with honey. On that occasion the wasp waded through the honey and escaped on the opposite side. After wandering about, partly on foot and partly on the wing, it returned to the honey, and when it had supped, backed away without getting into it.

These wasps also displayed an instinctive tendency to drink water under a variety of conditions. They were noticed to drink from a watch-glass partly filled with mud, from the outside of that watch-glass, and from the cloth syphon that supplied the watch-glass with water. One was noticed to enter the bent-neck bottle, drink and back out. The sipping of the honey and the drinking of the water occurred both in the bright light and in the shadow.

Responses to Brightness. In this species brightness usually serves as a stimulus to activity and darkness or a dim light as a stimulus to inactivity. As a rule, under the influence of a strong white light, these wasps would make active flights or else walk rapidly about. These responses were not tropisms, for the flights were pronouncedly random; there being no fixed relation between the direction of the movement and the rays of light.

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[3] In this article instinct is used to signify inborn responses.

Frequently several seconds, and occasionally a few minutes, would elapse between the impinging of the light rays and the responses of the wasps, and individuals climbing upwards through the sunlight, on reaching the upper edge of the bright patch, often continued to walk about in the shadow for sometime before coming to rest. In each of these cases the behavior might be considered due to the fact that it requires time for the stimulus to overcome the inertia of the nervous system; but, since, under exactly similar external conditions, the reaction times are quite different, certain physiological conditions, of which there were no external evidences, must influence the behavior. Then too, occasionally wasps would be quite active, for long stretches of time, when the external stimulus was a dim light; or else remain inactive, for equally long stretches of time, when exposed to a strong white light. Wasps, when feeding, frequently made no responses to a bright light. In this latter case it is highly probable that the stimulus of the food had a greater effect upon the hungry wasp than the light; but in the other cases there was no external indication of the physiological condition which caused the deviation from the usual type of response.

To ascertain if, in spite of the apparently random flights, *Trypoxylon albotarsus* might not have an instinctive tendency to move either towards or away from the light, at intervals, the positions of the wasps were recorded. Some of these experiments seemed to show conclusively a tendency to move towards or settle in the light (Exp. 4) some seemed to demonstrate an equally marked tendency to move towards or to settle in the shadow (Exp. 5), some seemed to indicate no more tendency one way than the other (Exp. 1). Sometimes, in the same experiment, one portion would indicate that the wasps had a strong tendency to move towards or to settle in the light (Exp. 2; 10:30, 10:35) while other portions indicated an equally strong inclination the other way (Exp. 2; 10:40, 10:45, 11:09, 11:15, 11:30). The only logical outcome of such a dilemma is to conclude that the movements were purely random. That these random movements were for the purpose of escaping from the cage is evidenced by the fact that whenever I made a small opening, whether in the bright light or in the shadow, whether in the side towards the source of the light or in some other side, one or more wasps always escaped or attempted to escape.

Responses to Shadows. In some experiments performed with some parasitic bees [4] which displayed a pronounced tendency to move towards the source of the light it was noticed that bees climbing upwards through the sunlight, on reaching a shadow, almost invariably dropped backwards. Careful observations were made to see if these wasps, which did not exhibit a pronounced tendency to move towards the source of the light, responded in the same manner to shadows encountered under similar conditions. As a rule, when these wasps reached the shadow they either moved on into it or else turned through an angle of 90 degrees and walked along the border line between the light and shadow. In a few cases, less than three per cent of those observed, the wasps dropped back when they reached the shadow.

Responses to Hues. Numerous experiments with colored lights, a few of which have been recorded under series IV, were conducted, not to test the visual powers of wasps, but to ascertain if certain rays stimulated a stronger response than other rays. As to the effect of hues as such the experiments were noncommital. The brightness content, however, seemed to play an important role. When a light stimulus, no matter what the hue, followed one with a lesser brightness content, the wasps usually became active; but when it followed one of greater brightness content the wasps usually became inactive. The orange was the most transparent glass, the blue next and the ruby least. Whether the orange followed twilight brightness, or the blue or the ruby, it usually stimulated the wasps to action. Unfortunately no experiments were made with the orange following a bright white light. When the ruby followed twilight darkness (Exp. 14) usually the wasps were stimulated to activity; but when it followed a bright white light (Exp. 18) or a blue light (Exp. 21) the wasps usually became quiet. When the blue light followed a bright white light (Exp. 6, 8, 10), in a few seconds, the wasps usually became quiet; but when it followed ruby (Exp. 22) the wasps were stimulated to activity. In about 85 per cent of the experiments the responses were as stated above; but the exceptions were too numerous to permit one to predict, with certainty, the response that will follow the use of a certain colored light as a stimulus. I have known the blue to follow a bright white light (Exp. 20) without causing the wasps to become inactive, and I have also noticed other incongruous responses.

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[4] Journal of Animal Behavior, 1911, Vol. 1, pp. 374–392.

When exposed continuously to an activity-inducing stimulus, *Trypoxylon albotarsus* exhibited a rhythm in its behavior. It would be active for a while, take a rest and then become active again. The cause of this rhythm was not apparent. One who has watched these wasps in the open could hardly believe the rest due to fatigue; for the amount of exertion and the time of activity were much less than what is exhibited by wasps afield. The pause may simply have been the result of the failure to find a means of escape. That the wasps were trying to escape is evident; for, when the wasps were actively flying about, no opening could be made anywhere in the cage without one or more wasps escaping or trying to escape.

NOTES

NOTE ON WILDNESS IN DUCKLINGS

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The writer was much interested this year in the behavior, as regards wildness, of certain young ducks hatched under hens. The common, so called "English Mallard" of the English game preserves has long been kept by man and acts at all ages like an extremely tame bird. It is a pure pred Mallard, but how long it has been under domestication is not known. It flies readily.

Not until this year, however, were my pure wild Mallards, *Anas boschas,* induced to lay. The eggs were taken, three nestfuls, placed under hens and hatched. They hatched well, and from the first the young ducklings were extremely tame and easy to manage. They took ordinary feed off the ground, and grew well in competition with other larger ducks in the same enclosure, though at all ages they preferred sunken or floated food. They differed from common ducks as regards their behavior in being much quicker on their feet and livelier in action. From the first they showed great skill and interest in catching insects.

At the same time there were hatched a large number of back crosses between common tame Mallards and pure wild Black Ducks, *Anas tristis.* One of these crosses produced young which were three-fourths *Anas tristis,* while in two other crosses the young were only one-fourth *A. tristis.* The three-fourth *A. tristis* ducklings, although raised under the same conditions as the wild Mallards showed from the first extraordinary wildness. They were extremely hard to manage, did badly under ordinary methods of hand rearing, and required much special care and special feeding. Even then the mortality among them was enormous, while among the wild Mallards it was practically zero. Besides their extreme wildness, the most noticeable trait of the three-fourth *A. tristis* ducklings was their marked aversion to picking food off the ground. Food *had* to be floated on the water pans or submerged. This habit of course, is also commonly seen in ducklings of other wild species, such as Pintails (*Dafila acuta*).

The one-fourth *A. tristis* hybrid ducklings were at first very wild, far wilder than the pure wild Mallards, but they changed with age and became much more like ordinary ducks. They did not show any special aversion to taking food off the ground.

In the wild state *Anas tristis* and *Anas boschas* are very similar in habits and commonly intermingle, *Anas tristis* being more of a coastal bird and having a different breeding area. The different actions of the young under confinement is very interesting, showing in the one bird an adaptability little short of marvellous, and in the other closely related species a condition that would wholly prevent domestication and almost prevent breeding in the pure state. I may say that the female of *A. tristis* very rarely lays eggs in capitivity, though the male crosses quite readily with other species. A control in the behavior of the pure wild Mallards was obtained by a number of young hatched by these same mothers in a secluded inclosed pond. These young are as wild as any wild ducks in the open, and it is rarely that one is able to get even a glimpse of them. *Their wildness then is immediately modifiable in the rearing yard.*

Behavior such as is carried by *A. tristis* certainly seems to be of a markedly dominant character and analagous to that seen in half bred wild rats and hybrid mice between wild and tame stocks.

Whether there is any tendency to a segregation of traits of this sort remains to be studied, but to the writer it does not seem as if this work would be at all easy or satisfactory to carry out among ducks.

SINGING MICE

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In the literature of animal behavior appear several references to the production by mice of sounds of musical quality.

The "singing" of mice is described variously by different writers. Lee[1] states that it consists of a series of chirps at the rate of three or four per second. At the beginning of the series, the chirps are low but gradually they become louder. The "song" of one mouse this author likens to the sweet and varied warbling of a canary. Every note was "clear and distinct."

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[1] Lee, Henry. Singing Mice. *Popular Science Monthly*, 1878, Vol. 14, pp. 102-105.

In referring to the same phenomenon, the naturalist Brehm,[2] attributes the following descriptions to various observers. One informant states that the "song" is an irregular mixture of chirps and trills with here and there a snarling, smacking sound followed by a low murmur. Another describes it as a twitter which is a mixture of long drawn squeaking and piping sounds which may be heard at a distance of twenty paces.

One observer noted the phenomenon only in the case of a female mouse while giving birth to young, while another observer states that only the male sings.

The majority of those who have heard "singing" in mice have assumed that it is due to a diseased condition of the lungs or of the vocal organs, but conditions so diverse as pregnancy and parasites in the liver have also been suggested as causes.

The writer desires to add to the observations already reported an additional record of "singing" mice. About the first of December, 1911, while working one evening in his study, he heard a series of sounds which seemed to come from above the ceiling. At the time, they were thought to resemble the soft chirp of a bird.

Shortly afterward, some wild mice were needed for breeding experiments and, by means of a trap, two mice, a male and a female, were captured in the room.

These animals, while being taken to the Harvard Psychological Laboratory, produced sounds like those previously heard in the room and they continued to do so at intervals after being placed in a laboratory cage.

A few days after their capture, the male escaped. The female was mated with a tame mouse and produced, during the period of observation, five litters, thirty-three individuals. None of these offspring of the mating of "singing" mouse with non-singing individual produced unusual sounds, nor has "singing" appeared either in the second or the third (F_2, F_3) generations.

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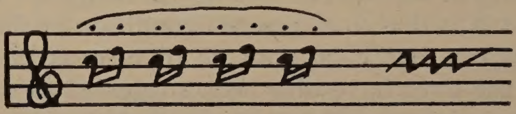
[2] Brehm, A. E. The Life of Animals. Chicago, 1896, p. 338.

Additional references: Shuffeldt, R. W. Natural History of the United States. 1897, p. 420. Ingersoll, E. Life of Mammals. New York, 1906, p. 429. Encyclopedia Americana. Vol. 10, Mouse. New International Encyclopedia. Vol. 14, Mouse. Riverside Natural History. Vol. 5, p. 109.

The "singing" individual was, so far as could be ascertained, a common house mouse (*Mus musculus*). She was somewhat larger than the ordinary wild female, but no other external peculiarities were noted. She was extremely active and savage and her mate always bore the marks of her teeth. An attempt to mate her with a second tame male resulted in the death of the latter.

No definite time for "singing" was noted, except three or four days before and for six or seven days after the birth of a litter. It was observed, also, that the individual "sang" sometimes when frightened.

The sound is best described as a rapid whole-toned trill involving the tones *c* and *d*, as is indicated below.



The quality of the tone resembled somewhat that of a fife or flute, but each tone ended with a slight throaty click. The tones were uttered at the rate of four or five per second in groups of varying size. Sometimes, a group occupied one second, sometimes as long as ten seconds. As a rule, the tones of a group were not clear and distinct but, instead, were uttered so rapidly as to seem connected. The throaty click was more noticeable in the case of the last tone of a group. Often the "singing" would be continued for a period of ten or fifteen minutes with rests between groups.

The sound could readily be heard at a distance of fifteen or twenty feet, but it was difficult to localize it. The individual "sang" little during June, 1912, and it was not heard after July 1st, 1912. She died in August, apparently of old age.

During May, 1912, "singing" was again heard in the room in which the "singing" mice had earlier been captured, but efforts to capture the "singer" failed.